SIMPLIFIED METHODS FOR VENT DISPOSAL SYSTEM SIZING FOR RUNAWAY CHEMICAL REACTIONS: EC AWARD PROJECT GUIDANCE FOR SMEs

J A Hare[1], A J Wilday[1], A Owens[2]
[1]Health and Safety Laboratory, Harpur Hill, Buxton, Derbyshire, SK17 9NR, United Kingdom
[2]Arran Chemical Company Ltd., Monklands Industrial Estate, Athlone, Co Roscommon, Ireland

The EC AWARD project had an objective to produce a design methodology for disposal systems to protect the environment from pressure relief of runaway chemical reactions. One required output was simplified guidance suitable for SMEs. The needs of SMEs are discussed. Simplified sizing methods, which are documented in the HSE Workbook for Chemical Reactor Relief System Sizing (Etchells, 1998), have been compared with large-scale experimental results from the AWARD project. Based on this limited comparison, recommendations are given for the estimation of:

- The quantity of material vented to the disposal system.
- The flow rate to the disposal system.
- The pressure in the reactor (which is an input to calculating the flow rate).

KEYWORDS: disposal system sizing, relief system sizing, level swell, runaway chemical reactions, guidance for SMEs

INTRODUCTION

Pressure relief of a runaway chemical reaction in a batch reactor can often vent a two-phase mixture and a disposal system is required that protects the environment. The sizing (of both relief system and disposal system) depends on how much liquid is vented i.e. level swell. Sizing depends on the flow rate to the disposal systems i.e. the relief flow rate. There is some guidance on disposal system sizing, the most comprehensive of which is the CCPS Guidance for Pressure Relief and Effluent Handling Systems (CCPS, 1998). This describes sizing methods for quench tanks, separators, total containment systems, scrubbers and flares.

The Advanced Warning and Runaway Disposal (AWARD) project (G1RD-2001-00499) ran from 2001–2005 with support from the European Commission under the Framework 6: Competitive and Sustainable Growth Programme. The project had two main objectives:

- The development of an early warning detection system (EWDS) to detect and prevent runaway, and

- To produce a design methodology for disposal systems to protect the environment from pressure relief of a runaway chemical reaction.

This paper is concerned with the second objective and, in particular, with the use of simplified sizing equations to specify the quantity and flow rate of material from a reactor emergency pressure relief system into a disposal system. It is intended to give industry, including SMEs, access to the project results. The AWARD project undertook large-scale (2.2 m^3) vented runaway experiments (Snee, 2006), which have been used for comparison with sizing methods. Further information about the AWARD project is available on the project website AWARD (2005).

COMPARISON OF HAND CALCULATIONS WITH AWARD LARGE SCALE EXPERIMENTS

INTRODUCTION

The aim of the AWARD project was to provide guidance on disposal system sizing by means of addressing the gap in existing guidance. While the CCPS "Guidelines for Pressure Relief and Effluent Handling Systems" gives excellent guidance on disposal system sizing, it requires inputs in terms of:

- the quantity of liquid entering the disposal system and
- the flow rate of the two-phase mixture (which depends on the sizing of the pressure relief system).

Calculation methods for these were therefore compared with experimental measurements. The large-scale experiments were designed primarily to measure level swell and this meant that the vent area was smaller and overpressure higher than in most pressure relief designs. However a comparison with available simple sizing methods was also carried out and is described below.

The HSL large scale facility used for the AWARD experiments consists of a reactor (capacity 2.2 m^3); an 8″ nominal bore vent line with an automatic valve and the provision of a restricting orifice and a dump tank (capacity 13 m^3). For all AWARD large-scale experiments the diameter of the restricting orifice diameter was 100 mm and the set pressure was 200 kPa. Some experiments included a surfactant to make the reaction mixture foamy. The AWARD large-scale experiments are described in Snee (2006). Key experimental results relevant to vent sizing and disposal system sizing are summarised in Table 1. The source of the experimental data is indicated in brackets.

RELIEF SYSTEM SIZING

The HSE produced a Workbook (Etchells, 1998), which gives information on methods available for the sizing of emergency relief systems for exothermic runaway reactions in liquid-phase chemical reactors. The Workbook, which is also available on-line, describes hand-calculation methods for relief sizing. These are simplified formulae that

Table 1. Experimental results – Relief and disposal system sizing

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Nominal batch mass (kg)	1266.2	1520.6	1777.6	1266.2	1520.6	1777.6
Maximum pressure (kPa)	360.6	604.9	677.9	576.4	719.2	771.6
Mass remaining in reactor (kg) (differential pressure)	883.2	774.9	624.9	351.0	349.3	357.4
Mass remaining in dump tank (kg) (differential pressure)	382.9	745.7	1152.7	907.5	1163.4	142.18
Duration of reactor venting (s) (pressure trace)	74.5	49.4	62	33.4	46.1	54.9
Duration of two-phase flow (s) (densitometer)	26.2	32.6	47.7	29.4	44.3	33.5

can be evaluated using a pocket calculator, so specialist software not required. The formulae were mostly developed during the US DIERS (Design Institute for Emergency Relief Systems) research project (1980s–90s). The DIERS project was summarised in the DIERS Project Manual (AIChE, 1992).

See the nomenclature for the symbols and definitions used in this section. The calculation of the vent area (A) is a two-stage process. The required relief rate (W) is first calculated. This is the mass flowrate, which must be removed from the reaction vessel in order to prevent overpressurisation. Secondly, the relief system capacity (G) is calculated. This is the mass flowrate per unit area through the pressure relief system. The vent area is then calculated as:

$$A = W/G \tag{1}$$

The large-scale AWARD experiments were on a vapour pressure system, the hydrolysis of acetic anhydride. The required relief rate (W) for vapour pressure systems can be calculated by the following methods which are described in the HSE Workbook (Etchells, 1998): Leung's method, Huff's method, Fauske's method, Wilday's stepwise method, Wilday's method with disengagement and Leung's bubbly/churn-turbulent methods. Leung's Equation is

$$W = m_R q/[\{(V/m_R)(h_{fg}/v_{fg})\}^{0.5} + \{C_f \Delta T\}^{0.5}]^2 \tag{2}$$

The flow capacity (G) can be calculated by Leung's Omega method, which is described in the HSE Workbook. In the Omega method, the dimensionless mass flux G* and critical pressure ratio are first obtained, then corrections are made for friction $(G/C_c)_{friction}$ and backpressure $(G/G_c)_{backpressure}$. Finally, the flow capacity is calculated using the following equation:

$$G = G^*(P_o/v_o)^{0.5}(G/C_c)_{friction}(G/G_c)_{backpressure} \quad (3)$$

Vent sizing spreadsheets were developed by the Health and Safety Laboratory from the HSE Workbook to facilitate calculations for the large-scale experiments. Some methods to calculate the required relief rate (W) assume conditions in the reactor are homogeneous. These are the methods of Leung, Fauske and Huff. The methods of Fauske and Wilday take account of level swell in the reactor to predict the point at which disengagement occurs.

Level swell is characterised by either the bubbly or churn-turbulent models. Disengagement void fractions required for the churn-turbulent calculations were obtained using the method outlined in Annex 3 of the HSE Workbook. Level swell methods are also discussed later in this paper. These are void fractions at the end of two-phase relief for relief sizing purposes (Workbook Eqn A3.1, calculated at maximum pressure). Churn-turbulent void fractions were calculated with correlation parameter, C_o, values of 1 and 1.5. Calculations for the bubbly and droplet flow regimes did not generate realistic solutions. The experimental and calculated disengagement void fractions are compared in Table 2. Experimental void fraction measurements were available from two sources: from a gamma ray densitometer and from differential pressure measurement. From the separate measurements, void fractions were estimated at different heights in the vessel. Disengagement was identified as when lack of homogeneity began to develop in the void fraction measurements, toward the end of the reactor venting.

Table 2. Disengagement void fractions – Relief system sizing

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Experiment (differential pressure)	0.545	0.586	0.664	0.813	0.811	0.806
Experiment (densitometer)	0.645	0.665	0.695	0.825		0.815
Calculated churn-turbulent ($C_o = 1$)	0.936	0.908	0.905	0.901	0.870	0.867
Calculated churn-turbulent ($C_o = 1.5$)	0.638	0.625	0.623	0.621	0.607	0.605

Table 3. Calculated vent diameters

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Experiment (mm)	100	100	100	100	100	100
Leung's method (homogeneous) (mm)	318	193	188	181	157	158
Fauske's disengagement method (churn-turbulent $C_o = 1$) (mm)	199	135	136	124	115	120
Wilday's disengagement method (churn-turbulent $C_o = 1.5$) (mm)	252	155	158	132	121	128

Leung's method (Workbook 6.3.2) was used for homogeneous vessel venting and Fauske's disengagement method (Workbook A5.3.4) or Wilday's disengagement method (Workbook A5.5) as appropriate (each method has its own validity criteria) for churn-turbulent vessel venting. Churn-turbulent vent sizes were calculated using correlation parameter, C_o, values of 1 and 1.5. The experimental and calculated vent diameters are compared in Table 3.

Churn-turbulent vent sizing calculations with $C_o = 1$ normally give larger vent sizes than those with $C_o = 1.5$. The opposite effect is apparent in Table 3 because Fauske's method was valid when $C_o = 1$ and Wilday's method when $C_o = 1.5$. For high overpressures, Leung recommended that the heat release rate per unit mass (q) be calculated using the Boyle time (revised method – Workbook Eqn 6.3) rather than from the average self heat rate (traditional method – Workbook Eqn 6.2). The effect of using the revised value of q rather than the traditional value is shown in Table 4.

The effect of maximum pressure on the vent diameter was also examined for both homogeneous vessel venting (Figure 1) and churn-turbulent ($C_o = 1$) vessel venting (Figure 2). The experimental maximum pressures shown in the figures are the same as in Table 1. Again, Leung's method was used for homogeneous vessel venting and Fauske's disengagement method or Wilday's disengagement method as appropriate for churn-turbulent vessel venting.

The conclusions of the comparison of the vent sizing calculations against the large-scale experiments were as follows:

For the vent sizing calculations:

- The vent sizing methods were generally conservative.
- The homogeneous vessel assumption was very conservative while the churn-turbulent vessel assumption was less conservative

Table 4. Calculated vent diameters – Revised q

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Experiment (mm)	100	100	100	100	100	100
Leung's Method (homogeneous) (mm)	321	214	214	200	186	190
Wilday's disengagement method (churn-turbulent $C_o = 1.5$) (mm)	253	172	180	145	144	155

- The vent sizing methods were less conservative for the tests with surfactant.
- Churn-turbulent vent sizing with $C_o = 1.5$ can give larger vent sizes than $C_o = 1$, if the vent sizing method used has to change because of the applicability criteria.
- Using a q based on Boyle time makes the vent size even more conservative.
- Because the vent sizing methods were conservative, the experimental maximum pressure is lower than the calculated maximum pressure, for a given vent diameter.

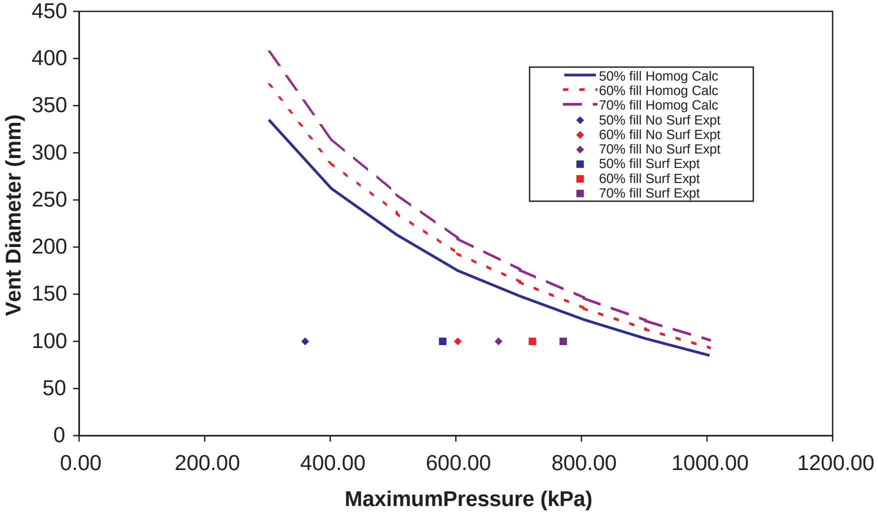

Figure 1. Homogeneous vent diameters

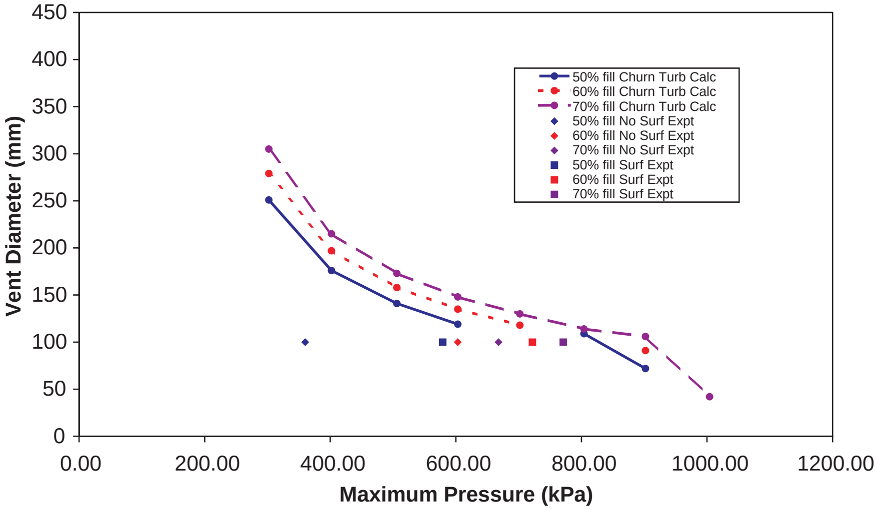

Figure 2. Churn2-turbulent vent diameters

The comparisons showed that the sizing methods were conservative for these experiments. The assumptions of the sizing methods are described in Etchells (1998). However, there was evidence that these assumptions were invalid, see Snee (2006).

For the level swell methods used for vent sizing:

- Without surfactant, the calculated disengagement void fractions were gross over-predictions for $C_o = 1$ and in good agreement for $C_o = 1.5$.
- With surfactant, the calculated disengagement void fractions were slight over-predictions for $C_o = 1$ and gross under predictions for $C_o = 1.5$.

DISPOSAL SYSTEM SIZING

Disengagement void fractions required for the churn-turbulent calculations were obtained using the method outlined in Annex 3 of the HSE Workbook. Calculations for the bubbly and droplet flow regimes did not generate realistic solutions. Churn-turbulent void fractions at the end of two-phase relief for disposal system sizing (Workbook Eqn A3.2 at the maximum pressure – note that g in the equation is a subscript to the ρ) were obtained. This calculation method assumes that disengagement occurs during depressurisation after the reactor pressure has peaked. The experimental and calculated disengagement void fractions are compared in Table 5. The experimental data is identical that to that in Table 2. The churn-turbulent void fractions were calculated using correlation parameter (C_o) values of 1 and 1.5.

The mass vented can be calculated assuming homogeneous venting (the entire batch mass is vented). It can also be calculated using the disengagement void fraction for disposal

Table 5. Disengagement void fractions–Disposal system sizing

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Experiment (differential pressure)	0.545	0.586	0.664	0.813	0.811	0.806
Experiment (densitometer)	0.645	0.665	0.695	0.825		0.815
Calculated churn-turbulent ($C_o = 1$)	0.756	0.752	0.752	0.76	0.76	0.761
Calculated churn-turbulent ($C_o = 1.5$)	0.549	0.546	0.546	0.551	0.551	0.551

system sizing. The calculation method is explained in the Workbook A3.3.5 – End of Two-Phase Relief. The experimental and calculated mass vented are compared in Table 6. The experimental data was obtained from differential pressure measurements.

The experimental and calculated mass fluxes (flowrate per unit area) are compared in Table 7. The calculated values were also used in the vent sizing calculations. Two experimental mass fluxes were available: An average mass flux calculated from the longer venting duration (includes single phase flow periods) and a two phase mass flux calculated from the shorter two phase duration. Both times are given in Table 1.

The conclusions of the comparison of level swell methods (for disposal system sizing) against the large-scale experiments were as follows:

Without surfactant:

- Calculated disengagement void fractions were slight over-predictions for $C_o = 1$ and slight under predictions for $C_o = 1.5$.

Table 6. Mass vented

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Experiment (differential pressure) (kg)	382.9	745.7	1152.7	907.5	1163.4	1421.8
Calculated homogeneous (kg)	1266.2	1520.6	1777.6	1266.2	1520.6	1777.6
Calculated churn-turbulent ($C_o = 1$) (kg)	793.5	1056.5	1316.3	815.3	1077.7	1337.4
Calculated churn-turbulent ($C_o = 1.5$) (kg)	391.9	670.6	933.3	422.7	691.4	951.1

Table 7. Mass flux – Pipe

	No surfactant			Surfactant		
Fill (%)	50	60	70	50	60	70
Experiment (average) (kg/m^2 s)	635.1	1865.3	2297.5	3357.5	3118.5	3200.3
Experiment (two-phase) (kg/m^2 s)	1806	2826.6	298.6	3814.4	3245.2	4949.2
Calculated (Omega method) (kg/m^2 s)	1253.1	2104.2	2249.2	2026.9	2312.6	2426.5

- Churn-turbulent: The calculated mass vented was over predicted for $C_o = 1$ and under-predicted for $C_o = 1.5$.
- Homogeneous: The calculated mass vented was grossly over predicted.
- The experimental mass fluxes were close to the calculated values.

With surfactant:

- Calculated disengagement void fractions were slight under-predictions for $C_o = 1$ and gross under predictions for $C_o = 1.5$.
- Churn-turbulent: The calculated mass vented was under-predicted for $C_o = 1$ and grossly under-predicted for $C_o = 1.5$.
- Homogeneous: The calculated mass vented was significantly over predicted.
- The experimental mass fluxes exceeded the calculated values.

NEEDS OF SMEs IN THE CONTEXT OF VENT DISPOSAL SYSTEM SIZING

CLASSIFICATION

According to the limited statistical data available, it is suggested that chemical industry SMEs in the European Union may be classified as follows:

- Companies engaged in chemical synthesis, which will have laboratory operations with control systems, and at least some chemical technology. We might define these companies as engaging in "intentional chemistry".
- Companies engaged in mixing, blending, possibly with some chemical reaction. These companies may have QC and application labs, but possibly not control systems or much general chemical expertise. We might define this as an "intermediate level" of chemical activity.
- Companies with "peripheral chemical activity" and no specific chemical know-how.

It is estimated that there may be 30–40,000 SMEs in the twenty five-member EU, with a large group of companies employing less than 10 people, and somewhat smaller groups employing between 10–100 employees and 100–250 employees respectively.

PRACTICAL CONSTRAINTS

By comparison with larger companies, it will be clear that SMEs have more limited financial and management resources, and this will be particularly true for the smaller companies. SMEs tend to focus on a specialisation of some kind, often using a proprietary technology, and as cost/benefit considerations are critical, they will tend to use conservative engineering design. Specific technical operations in this industry will usually involve batch or semi-batch reactions in standard equipment design. Resource constraints and technical sophistication will vary enormously in the EU SME sector. The needs of a specific company, and the appropriate level of guidance required will depend very much on whether the companies are engaged in "intentional chemistry", or "peripheral chemistry".

It might be argued that those engaged in intentional chemistry are at least aware of the need for a screening framework to cover exothermic reactions, but may need more or less help in implementing a suitable system. On the other hand for companies engaged in "peripheral chemistry", or even those at an "intermediate level", this need may not be so clear, especially for smaller companies with less resources.

The SME sectors are important employers in the EU, and because SMEs often have specific technical expertise, perhaps related to specialised or innovative or proprietorial technology, they are important in the Community as innovators.

Because SMEs have relatively limited resources, whether financial or personnel related, there can be problems for them interfacing with outside agencies whether regulatory authorities, or consultants and contractors or providers of related services. These problems can include:

- The complexity of legal framework and the uncertainty of application.
- Problems caused by "over regulation" where the implementation of a specific law or directive may take a disproportionate amount of resources. It is acknowledged, in this context, that the European Commission and the European Parliament are concerned to reduce the bureaucratic burden for SMEs, but much remains to be done.
- The varying degrees of awareness and technical ability within the individual SME.
- The lack of understanding by some external agents of the cost and time constraints on SMEs.

GUIDANCE FOR SMEs

A short guideline document aimed at SMEs has been written (Hare, 2005) which appears on the AWARD web site under "Guidance for SMEs". The guidelines were made available initially in draft form and finalised after comment by the partners and industry.

The guidelines provide information on the use of hand-calculation methods for estimating the input to disposal sizing methods. They also cover the context of the basis of safety for chemical reactions, sources of further information and the work done within the AWARD project as a whole. Recommendations are given for inputs to the sizing of disposal systems. The main sources of guidance identified are outlined below together with a brief summary of some of the topics covered:

PREVENTION AND PROTECTION AGAINST RUNAWAY REACTION

There is a lot of existing guidance available on the assessment of chemical reaction hazards, the choice of an appropriate basis of safety and, should the basis of safety be pressure relief, on the sizing and design of the emergency pressure relief system.

Assessment of chemical reaction hazards is crucially important so that the hazards are fully understood. The Thematic Network on Hazard Assessment of Highly Reactive Systems (HarsNet) has produced two documents which are available on-line: HarsBook (a source of background and reference material on the subject of exothermic reaction hazards) and HarsMeth (a short cut chemical process safety assessment specially designed for SMEs). Other guidance on chemical hazard assessment includes: HSE (2000), Barton (1995) and CCPS (2001).

Emergency pressure relief is a commonly used basis of safety against runaway reaction. The HSE "Workbook for chemical reactor relief system sizing" (Etchells, 1998) gives information on methods available for the sizing of emergency relief systems for exothermic runaway reactions in liquid-phase chemical reactors.

CCPS (1998) also gives guidance on emergency pressure relief sizing but assumes that such sizing will be carried out using commercially available specialist software packages. It also includes a CD-ROM, which allows calculation of two-phase flow rate using a number of simplified approaches.

CONTAINMENT/DISPOSAL SYSTEMS FOR EMERGENCY PRESSURE RELIEF

A containment/disposal system to protect the environment is recommended in recent BREF guidance notes (EIPPCB, 2005) under the EC Integrated Pollution Prevention and Control (IPPC) Directive, and a suitable assessment may be required. The actual system will depend on the situation and the location and the sizing (of both relief system and disposal system) depends on how much liquid is vented i.e. level swell (see below). Sizing of disposal systems also depends on the relief flow rate. Whereas the use of bursting discs is widespread in the chemical industry, it might be appropriate for some SMEs in some circumstances to consider installing pressure relief valves (PRVs), which can reset, and may serve to limit the actual physical discharge.

The most comprehensive guidance available for disposal system sizing is the CCPS (1998), which covers:

- selection of the most appropriate type(s) of disposal system;
- sizing and design of common types of disposal system, including:
  - quench tanks,
  - separators,
  - total containment systems,
  - scrubbers,
  - flares.

The HSE Workbook (Etchells, 1998) suggests that the strategy for selection of a disposal system should be to deal with the two-phase nature of the discharge by quenching, separation or containment. The liquid needs to be collected for subsequent disposal. However, attention needs to be paid to stopping any continuing runaway. The gas/vapour may be suitable for discharge to atmosphere in a safe place, or may need further treatment by a scrubber or flare.

The purpose of the guidance for SMEs is to fill a gap in the available guidance. While CCPS (1998) gives excellent guidance on disposal system sizing, it requires inputs in terms of:

- the quantity of liquid entering the disposal system and
- the flow rate of two-phase mixture.

The CCPS Guidelines obtain this information from commercially available specialist software packages. The guidance for SMEs is mostly focussed at the use of simpler hand-calculation methods (such as those from the HSE Workbook) to obtain this information. However, the AWARD project was also concerned with validating and improving level swell methods implemented as software packages (Rogers, 2006) and some comments on these results are also given in the "Guidance for SMEs" document on the AWARD website.

LEVEL SWELL

Both the quantity of liquid and the flow rate depend on level swell within the reactor during pressure relief, and the AWARD project was focussed on improving the understanding of this.

A simple model of level swell is that, when gas or vapour is produced during a runaway reaction, it occupies space within the liquid as it seeks to rise to the top and disengage. This causes the liquid level to rise or swell. If it rises to the inlet of the relief system, then two-phase (gas/vapour and liquid) flow occurs in the relief system (see Figure 3). This needs to be taken into account when sizing the relief system, to ensure that it is large enough.

For relief disposal system sizing, the end of two-phase venting needs to be predicted. This will often occur after the pressure has peaked, when the reactor is

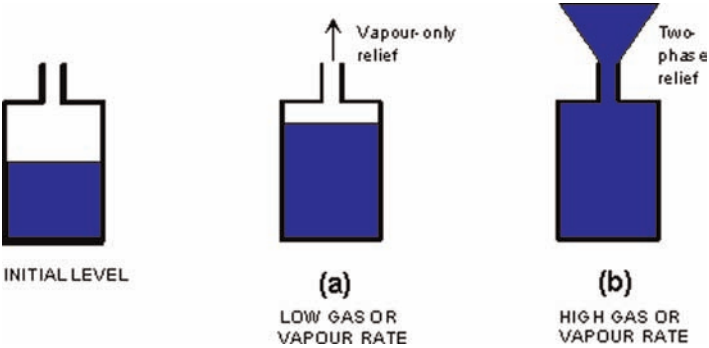

Figure 3. Effect of vapour rate on level swell

undergoing depressurisation back to atmospheric pressure, or to the set pressure of any safety valve. Depressurisation may cause flashing and/or dissolved gas to come out of solution.

AVAILABLE SIMPLE SIZING METHODS

It is not the purpose of the SMEs guidance to repeat sizing methods, which are already given, together with conditions of applicability and worked examples, within the HSE Workbook (Etchells, 1998). Users are directed to that publication for the methods themselves and for commentary, particularly with respect to relief system sizing.

The sizing methods can be used in different ways:

- To size the pressure relief system for a new reactor, dedicated to a particular process/product; or
- To determine operating constraints for an existing reactor, with existing relief system, when it is to be used for a new duty (reaction/process/product etc.). In this case, the batch volume, concentrations, feed rates, etc. may be restricted so that the worst case runaway can be handled by the existing pressure relief system. The possibility of reducing the relief set pressure may also be considered. Since the sizing methods are designed to calculate a required relief area, they may have to be used in a trial-and-error procedure to find operating conditions for which the available relief area does not cause the existing reactor design pressure to be exceeded. In real life, this will be a very important consideration, as SMEs will normally use standard reaction vessels, of standard dimensions and will carry out their batch processes in these. It is very important therefore, that sizing methods be used to determine and confirm maximum safe loading conditions for specific duties and reactions.

RECOMENDATIONS GIVEN

Based on the limited comparison between the simple sizing methods, the AWARD large-scale experimental results (on a vapour pressure system) and previous pilot scale experiments on vapour pressure and gassy systems; the following is concluded:

For systems that are not surface-actively foamy, an approximate estimate of the quantity of liquid vented to the disposal system can be obtained using the level swell methods detailed in Appendix 3 of the HSE Workbook (for estimating the end of two-phase flow). For systems that are foamy, it can be conservatively assumed that all the contents of the reactor vent to the disposal system, although significantly less was vented in the HSL large-scale experiments with surfactant.

For disposal systems which act as separators, the maximum two-phase flow rate into the disposal system is also required for sizing. The Omega method given in Appendix 8 of the HSE Workbook can be used to estimate this flow rate, using inlet conditions based on assuming a homogenous two-phase mixture in the reactor. For systems, which are not surface-actively foamy, this gave a conservative overestimate of the average flow rate but underestimated the maximum flow rate. For foamy systems, both the average and maximum flow rates were underestimated. A safety factor should therefore be applied to the calculated flow rate and the comparisons show that the factor of 2 suggested in the HSE Workbook was sufficient in most cases. For the experiment with surfactant and with the highest fill ratio, a factor of 2.5 was needed to estimate the maximum flow rate.

Relief sizing methods from the HSE Workbook can be used to estimate the upstream pressure for the calculation of the flow rate to the disposal system. Comparison with the AWARD large-scale experiments showed that these methods were conservative and so will tend to overestimate the maximum reactor pressure which is also conservative for estimating flow rate to the disposal system. Previous comparisons with pilot-scale vented experiments showed that the relief sizing methods for vapour pressure systems ranged from conservative to just adequate. Use of a safety factor as suggested in the HSE Workbook made the sizing methods conservative for all the experiments. For gassy systems, it is important to obtain calorimetric data from tests using open test cells, otherwise dissolved gas can lead to underestimation of the required vent size (or maximum reactor pressure for a given vent size).

CONCLUSIONS

As part of the European AWARD Project:

- The needs of, and the constraints on SMEs in this context have been outlined within the framework of a simple analysis.
- Simple sizing methods have been compared with large scale experimental results.
- A short guidance document aimed at SMEs has been generated.

DISCLAIMER

The opinions expressed in this paper are those of the authors and not necessarily those of the Health and Safety Laboratory nor the Health and Safety Executive.

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NOMENCLATURE

A	Cross-sectional flow area of relief system (m^2)
C_f	Liquid specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
C_o	Correlating parameter in level swell calculations
G	Flow capacity or mass flux ($kg\ m^{-2}\ s^{-1}$)
G^*	Dimensionless flow capacity or mass flux
G_c	Choked flow capacity or mass flux ($kg\ m^{-2}\ s^{-1}$)
$(G/C_c)_{friction}$	Correction factor in Omega method for friction
$(G/G_c)_{backpressure}$	Correction factor in Omega method for non-choked flow
h_{fg}	Latent heat of vaporisation ($J\ kg^{-1}$)
m_R	Mass in reactor at relief pressure (kg)
q	Heat release rate per unit mass ($W\ kg^{-1}$)
ΔT	Temperature difference between the temperature at the relief pressure and the maximum accumulated pressure (K)
V	Volume of reactor (m^3)
v_{fg}	Difference between vapour and liquid specific volumes ($m^3\ kg^{-1}$)
W	Required relief rate ($kg\ s^{-1}$)
ρ_g	gas density ($kg\ m^{-3}$)

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