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# Venting of Foaming Three-Phase Systems with Hydrophilic and Hydrophobic Particles

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The correct design of a safety valve or rupture disk can only be done if the venting behaviour can be predicted. When it comes to foaming or highly viscous systems those predictions meet up to date their limits. An experimental study is presented that describes the influence of particles hydrophilic properties on the venting of foamy systems. It is shown that hydrophilic particles increase the mass discharge over time and reduce the pressure decrease over time by increasing the foaming of aqueous systems. The particles itself are hardly vented. First experiments with hydrophobic particles also show an effect on the venting behaviour. The particles are vented at the beginning of the vent process drastically influencing mass discharge and pressure decrease over time.

## 1. Introduction

Excessive pressure is one of the major hazards in process industries. To protect containers like reactors and vessels from blow up rupture discs or safety valves are implemented as part of a safety concept.
Thriving parameter in the design of the right safety valve or rupture disc for a given setup is the minimal diameter in the line. The minimal diameter is highly influenced by various factors. The venting behaviour is influenced by the source of the excessive pressure in the vessel, the flow regime inside the venting device, the location of the venting device on the vessel or the density of the liquid media just to name a few. Each one of these factors derives the need for the fitting model to that precise purpose.
When only top vented lowly viscous vapour pressure systems are considered the possibilities are narrowed down to three major scenarios. Either single-phase flow consisting of vapour or two-phase flow consisting of vapour and liquid or three-phase flow with particles additionally to liquid and vapour can occur.
Single-phase flow can be modelled like the stream of vapour through a jet nozzle. Thus models for the determination of the minimal diameter fit the demands completely. Two-phase flow is more difficult to model. Effects like slip, radial dispersion profiles and thermo dynamical disequilibria have to be taken into consideration for precise results. Several models have been developed for modelling of this scenario. They range from conservative models that don't take any of the effects noted before into account like the Homogeneous Equilibrium Model (HEM) developed by the HSE (2006) to models considering most of them like the HNE-DS model of the ISO 4126-10 which is presented in the papers by Schmidt (2007). For three-phase discharge no influence of the particle has been shown to this point. Several works like the works from Poli et al (2009) or the HSE (2006) recommend a design as if it were two-phase flow.
All those models meet their limits if amphiphile components induce foaming during the venting. Up to date foamy systems are not modelled. The minimal diameter is rather set by over conservative assumptions that lead to drastic cost increases and in some cases unsafe conditions. The influence of particles on the venting behaviour is only scarcely described. Especially the direct influence of particles on the venting of foaming systems has not yet been described. To determine it foaming systems with and without particles are presented.

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## 2. Experimental Setup

Experiments are carried out in a modified RC1e by Mettler Toledo. An additional pressure sensor is added and a vent line that leads to an open 100 L vessel. The vent line is opened and closed electronically by a pneumatic ball valve. An aperture plate with a diameter of 2 mm is placed directly in front of the ball valve setting the minimal diameter in the vent line. Thus ball valve and aperture plate can be used to represent a rupture disc. The experimental setup can be seen in Figure 1.

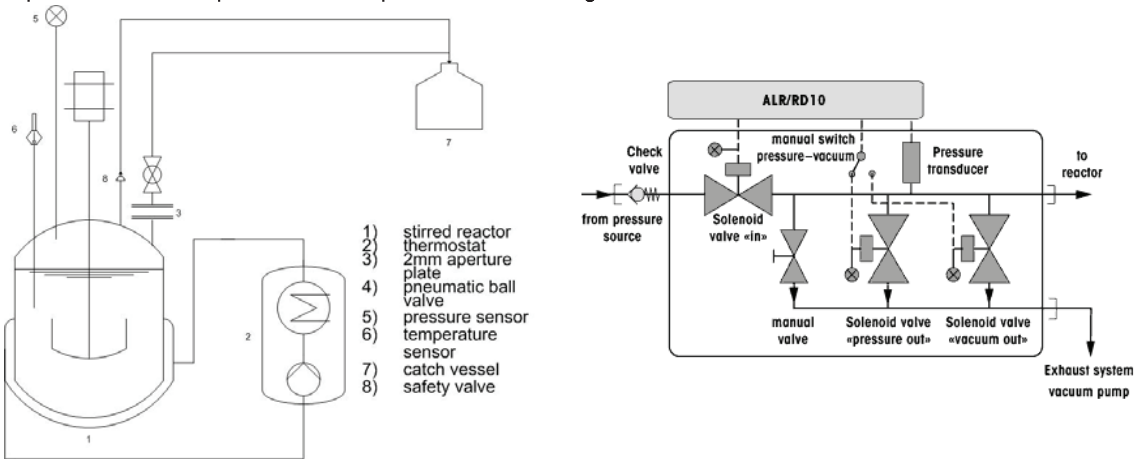


*Figure 1: Modified RC1e for venting experiments (left) and schematic design of the RD10 by Mettler Toledo (2012) (right)*

An RD10 pressure control loop by Mettler Toledo is additionally connected to the RC1e for experiments on foaminess of systems. A set of valves controls the flow from and to the reactor depending on wanted and actual pressure. Thus pressure increase or decrease over time can be controlled. The schematic design can be seen in Figure 1.

### 2.1 Systems and Parameters

The venting experiments were conducted in foaming aqueous non reactive vapour pressure systems. To induce the foaming two surfactants were used. Falterol is an industrial cleaner consisting mostly of sodiumdodecylsulfat (SDS) that has been used in quite a few venting experiments of foamy systems. To reduce side effects by additives in Falterol pure SDS is used also in a different set of experiments. When working with SDS in aqueous systems one has to take into account that SDS hydrolyses in water. An alcohol is formed that functions as co-surfactant and increases the foaminess of systems. Thus all experiments were prepared with a solution of at least 1 g/L that aged a minimum of 2 d before use.
As particles Silibeads are used. They are chosen since they have a perfectly round shape with a plane surface and are chemically inert. The full set of the experimental parameters can be found in Table 1.

*Table 1: Experimental parameters for venting experiments*

| Reactor volume | Filling level | Mass fraction of particles | Set pressure | Additives | Particles |
|---|---|---|---|---|---|
| 1.2 L | 80 % | 20 % | 6.0 bar | Falterol, sodiumdodecylsulfat | Silibeads 40-70 µm |

### 2.2 Measurement of foaminess

For the experiments on foaminess a pressure rate from 1.7 bar to 1.0 bar at the corresponding temperatures is performed. Thus a thermodynamic disequilibrium is induced and the system starts to boil. The created bubbles build foam on top of the liquid and the height is measured. This method has the advantage that the same fixtures and materials are used for measurements of foaminess and venting. Also the liquid phase and the gassy phase are at similar conditions as for the venting experiments.

## 3. Results

### 3.1 Foaminess

To show the effect of particles on the foaminess the system with SDS was chosen since it is a component in all systems. Figure 2 shows that the results indicate a strong influence of particles on the foaminess of foamy systems.

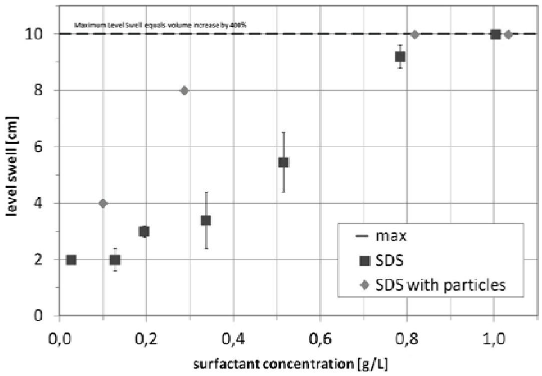


*Figure 2: Foaminess of SDS solutions with and without particles*

The level swell is given in cm. It is limited by the height of the reactor indicated by the dashed line. The initial fill level was at 4 cm. Figure 2 shows that already at low concentrations the foaminess is drastically increased by the particles. It is at least double until a concentration of 0.3 g/L. Afterwards precise interpretation is limited to the fact that the systems with particles reach the lid of the reactor earlier. At 1.0 g/L systems without particles also reach this limit and further increase wouldn't lead to additional results.

Reason for the increased foaminess is a stronger bubble production in three-phase systems than in those without particles. While in two-phase systems bubble nucleation and rise can only be observed on the metal fixtures in systems with particles bubble nucleation is also observed on the particles itself. Thus more turbulent regime arise that now spreads all over the cross section of the reactor.

### 3.2 Venting experiments

The results of the venting experiments with Falterol follow the results of the experiments for foaminess. Adding particles leads to significant effects in the pressure time curve and the mass discharge. An example for the pressure behaviour and the overall mass discharge can be seen in Figure 3.

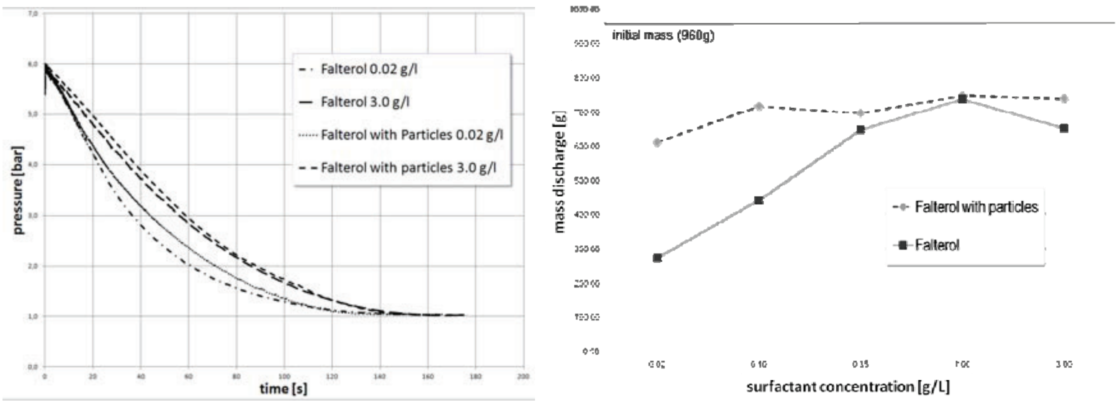


*Figure 3: Pressure time curve (left) and mass discharge (left) of venting experiments with Falterol*

It clearly shows that adding particles slows the pressure decrease over time. This is induced by the stronger foaming by the addition of the particles. This effect is extremely pronounced at low concentrations. At higher concentrations the pressure curves for two- and three-phase systems lay very close and almost cover one another.

The increased foaminess also leads to an increased mass discharge. This effect is more pronounced at low Falterol concentrations. At 0.02 g/L mass discharge is more than doubled. Significant solid discharge

is not observed. Both effects can be explained by a prolonged two-phase discharge. It appears that due an increased foaminess the level swell is higher and thus reaches the vent line for a longer period.
At concentrations larger than 1.0 g/L the influence of the particles lessens. Pressure decrease and mass discharge are similar to the ones of two
The results of the experiments with SDS differ in comparison. Although the similar effects can be seen in the mass discharge are the effects less pronounced.

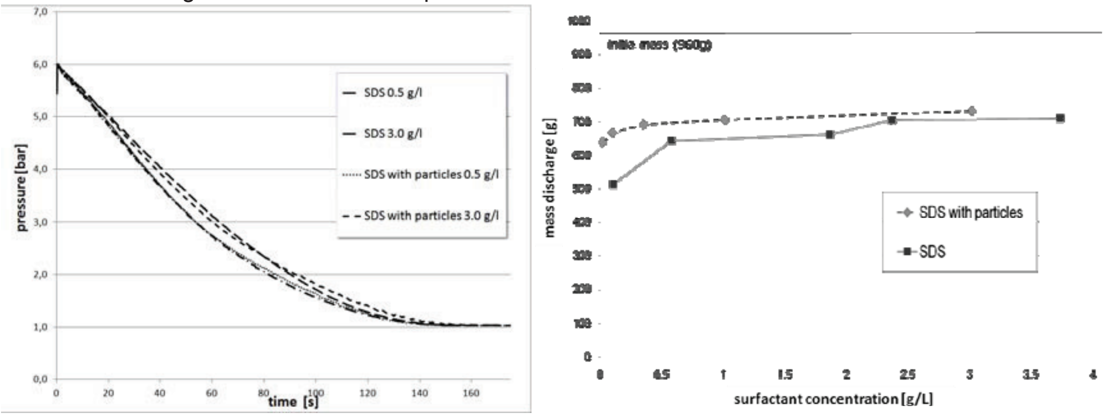


*Figure 4: Pressure time curve (left) and mass discharge (left) of venting experiments with SDS*

The mass discharge of three-phase systems is still larger than the one of two-phase systems. But it doesn't exceed a difference of 30 %. As in the results of Falterol the effects get smaller once higher concentrations are reached.
An effect of the particles on the pressure decrease over time is hardly observable. At the beginning of the venting the three-phase system's pressure decreases faster. At later times it slows down and crosses the two-phase curve again. This might be a result to a longer two-phase discharge with a lower mass fraction of the liquid at the beginning of the vent line.

**3.3 Influence of foaminess of venting behaviour**

To directly compare the effect of the foaminess on the venting the mass discharge is plotted against the level swell. The comparison is seen in Figure 5. An obvious direct dependence between the level swell and the mass discharge is seen. If the foaminess is the mass discharge rises. At the beginning this effect is quite pronounced. But it reduces when a relative mass discharge of 70 % is reached. This mass discharge is characterizes the point that a two-phase discharge is observe throughout the whole venting process. Afterwards only little changes can be observed. But still it follows the same patter no matter what system is considered.

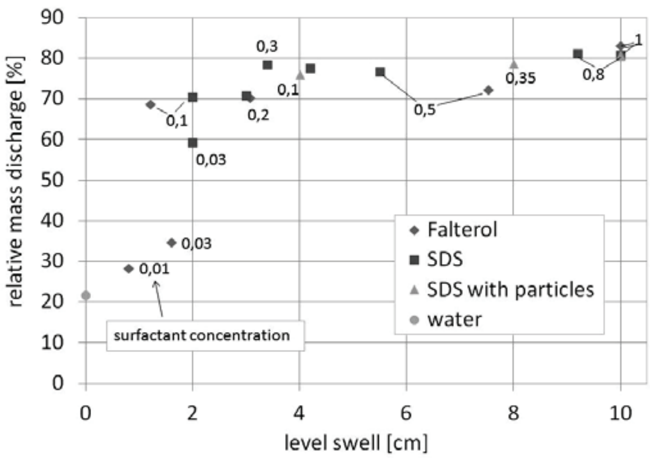


*Figure 5: Mass discharge over foaminess for systems containing SDS*

## 4. Systems with hydrophobic particles

Up to date only a few experiments have been carried out. Experiments were carried out in an ADCII by Chilworth Technology Ltd. Set pressure, mass fraction of the particles and fill level of the experiments equal those of the previously described setup.
Falterol is used as surfactant. PVC particles are used as solid. Results show completely different behaviour than the results with the Silibeads. The PVC particles are vented at the beginning of the vent process. Thus they partially block the vent line at the beginning of the experiment. This leads to a dramatically slower pressure decrease over time within the first 20-30 seconds of the experiment.
The mass discharge changes as well. The particles are almost completely vented as is the liquid. Further information on the experiments with the PVC particles can be found in Poli et al (2009).
The reason for the differences is due to the different hydrophilic properties of the particles. The major influence of hydrophilic properties on foam behaviour and stability has been described in different fields of research before. Joshi et al (2009) describe the use of hydrophobic particles to induce bubble coalescence in surfactant based solutions. In another study Wasan et al (2004) describe an increase of foaminess of systems with particles present and show that the effect is much stronger for biphilic particles than for hydrophilic particles. Furthermore Mata et al (1999) propose a major influence of the hydrophilic properties of particles in a fluidized bed on foam suppression.
In the case of the venting of the systems investigated hydrophobic particles clearly join the thin films of foam. Hydrophilic particles instead cannot join those layers. Thus they stay at the bottom of the reactor and cannot be vented.
This behaviour can also been seen in images taken during heat up before venting and the venting itself. Those images can be seen in Figure 6.

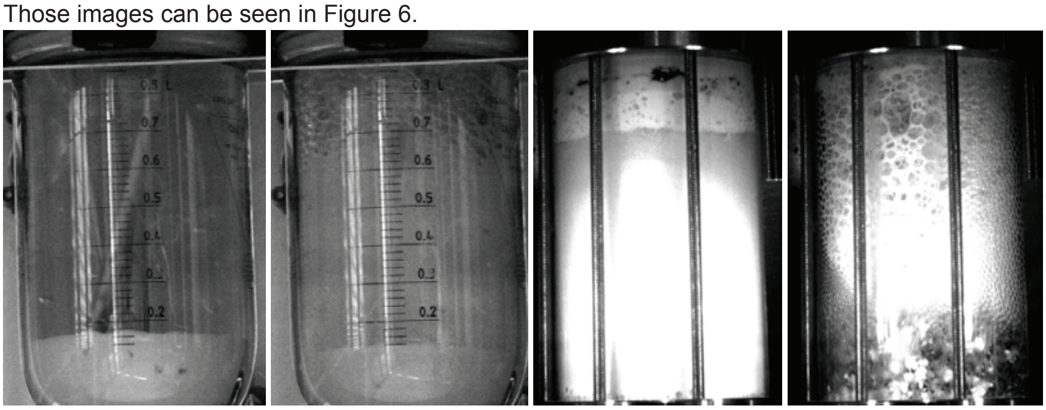

*Figure 5: Images of the reactor before (first) and while (second) venting for Silibeads in an RC1e by Mettler Toledo (left) and PVC particles in an ADCII by Chillworth Technology (right)*

During venting the foam structure in the systems with the Silibeads differs from the foam structure in systems with PVC particles. While in the Silibead systems dry foam with a polygonal structure forms the foam in the PVC systems is very wet and rather unstructured. Particles inside the fluid layers of the foam destabilize the structure and lead to thick liquid layers.

## 5. Conclusions

Particles show to have a great impact on the venting behaviour on foamy systems. They increase the mass discharge and decrease the pressure decrease over time. Venting of the particles itself depends on the hydrophilic properties of the particles. Hydrophilic particles are hardly vented. Hydrophobic particles are almost completely vented. This can lead to dramatic effects on the pressure curve over time but especially downstream of the venting device itself. Lines may be blocked and systems purposed for the after-treatment of the vented masses may not function properly. Thus hydrophobic particles have to be taken into account in hydrophilic systems.
To model foamy three-phase systems one should consider constant at least two-phase discharge due to increased foaminess and use models recommended for foamy systems. One approach to Model foamy systems can be found in the work of Schecker (2003).
Experiments with different particles will be carried out. Currently experiments are carried out that use Silibeads which are coated with a thin hydrophobic layer. They are showing similar tendencies as the PVC particles. Also it is considered to change the systems from aqueous media to an unpolar organic media. In

these systems the effects should be inverted. Instead of the hydrophobic particles the hydrophilic particles should be vented. Same effect may be reached by using an unpolar surfactant. Some results in the work of Poli et al (2009) in systems with Silibeads in an aqueous celluloid ether solution indicate that hydrophilic particles can be significantly vented in those systems as well.

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