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Sizing of rupture disks for two-phase gas/liquid flow according to HNE-CSE-model

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ABSTRACT

Industrial rupture disk vent line areas for two-phase flow are currently overestimated. As a consequence, the dischargeable mass flow rate is partially much higher than necessary often leading to malfunctions in downstream retention systems and increased environmental loads. For two-phase gas/liquid flow there is no standardized sizing procedure available. Hence, the homogeneous non-equilibrium model HNE-DS is transferred from sizing safety valves to a procedure for sizing rupture disk vent lines. Thermodynamic non-equilibrium effects like boiling delay are considered. The extend method is called HNE-CSE method.

Characteristic numbers of rupture disk vent lines like the resistance coefficient K_R are typically measured under laboratory, subcritical conditions with incompressible fluids, i.e. liquids or gases at very low velocities. In contrast, the flow typically encountered in an industrial rupture disk vent line is a compressible gas or two-phase gas/liquid flow under critical flow conditions. The sizing of a rupture disk vent line based on characteristics for incompressible fluids is therefore a challenge. An appropriate test section for compressible fluids as an extension of ASME PTC25 is recommended. In addition the definition of the resistance coefficient is extended to compressible fluid flows.

1. Introduction to rupture disk vent line systems

Most of the chemical, pharmaceutical and petrochemical plants are protected with classic end-of-pipe technology, typically a rupture disk or a safety valve connected to a disposal system or discharging to atmosphere. A rupture disk device consists of the rupture disk itself and a holder, which assures the sealing of the vessel inventory and provides an easier installation and replacement of spare parts. The rupture disk is essentially a thin single-use solid membrane designed to fail and enable the pressure relief at a certain pre-assigned pressure. After rupturing, it has to be replaced to ensure a safe process. To avoid any unintentional rupture of the disk in case of product release or due to reactor cleaning, vacuum supports are used in front of the rupture disks. Testing requirements of rupture disks shall be based on typical operational demands (Figs. 1–2).

Protection of pressurized vessels involves several layers of independent safety measures in different levels of safety integrity, which are based on the overall risk and loss potential that may possibly result from deviations from normal plant operation of a technical system. Rupture disk devices are usually not installed directly on a reactor. Instead, they are placed at a location where inspection and service can effectively be afforded. Typically, a relatively short inlet line connects the reactor with the rupture disk device mounted to an outlet line and further on to a gathering relief pipe outside the plant building. The gathering line leads into a separator and the gas is released over the roof into the ambient or in a quench, washer or flare. In the petrochemical industry, long and often large diameter rupture disk vent lines are used to discharge gas into a flare system (Friedel and Schmidt, 1993).

Critical flow conditions can be established at multiple locations, in the rupture disk or immediately behind an area change in the inlet and/or outlet line. During the relief of a vessel, the location(s) with critical flow may change. Hence, to size a rupture disk device under typical plant operating conditions, extensive fluid dynamic knowledge is necessary.

In contrast to safety relief valves, for rupture disks, as a non-reclosing overpressure/vacuum protection safety device (Smith

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and Zappe, 2004), the dischargeable mass flow rates are predominantly dependent on the flow resistance in the inlet and outlet lines. Hence, rupture disk devices and vent lines have to be considered as a combined relief unit. The mass flow rates of liquids and gases in case of emergency relief are highly dependent on the worst case scenario taken to size a rupture disk vent line, and the overestimation of the rupture disk net flow area due to the uncertainty of the sizing procedure. Based on the transient mass flow rate and pressure course, the sizing calculation of rupture disks, safety valves, separators, drums, scrubbers and flares are done. Besides the reactions forces, the pressure resistance and the toxic hazard potential is analyzed.

During the last twenty years a tremendous effort has been made in sizing relief lines for flashing two-phase flow by considering phase slip between gases and liquids (mechanical non-equilibrium) and boiling delay as the thermodynamic non-equilibrium effects. Both increased significantly the precision of sizing safety devices. To harmonize the methods for sizing safety valves and rupture disk vent lines (ASME-PTC25, 2009; ISO 4126-10, 2010), the HNE-DS model for flashing gas/liquid-two-phase flow through throttling devices, recommended in ISO 4126-10 (ISO 4126-10, 2010), is extended to the flow through pipes and rupture disk devices. In addition, a test facility is recommended to measure the characteristic numbers for rupture disk devices for both compressible gas and gas/liquid flow.

Current sizing procedures, e.g. (API RP-520., 2010), often highly overestimate the net flow area of a rupture disk device and the mass flow rates released through rupture disk vent lines, which may lead to huge extra costs, malfunction of downstream process equipment and additional environmental problems. A precise sizing procedure, especially for two-phase flashing flow, is lacking. Neither a test procedure is standardized nor are any measurements published.

2. Steps to size a rupture disk

5 steps are necessary to size a rupture disk vent line, Fig. 3: (1) the sizing case must be defined based on a risk analysis (HAZOP study) to identify the worst credible case out of all reasonable possible failures. (2) The flow regime at the entrance of the rupture disk vent line shall be estimated by means of the level swell in the pressurized system and (3) the minimum flow rate to be discharged must be determined. It is generally calculated by an energy and mass balance around the pressurized system. The following two steps belong to the sizing of the vent line system. Prior to a final calculation at (4) the geometry and size of the rupture disk vent line has to be estimated based on a simplified sizing computation and in the final (5) step, the estimation must be validated by a precise and detailed pressure drop calculation.

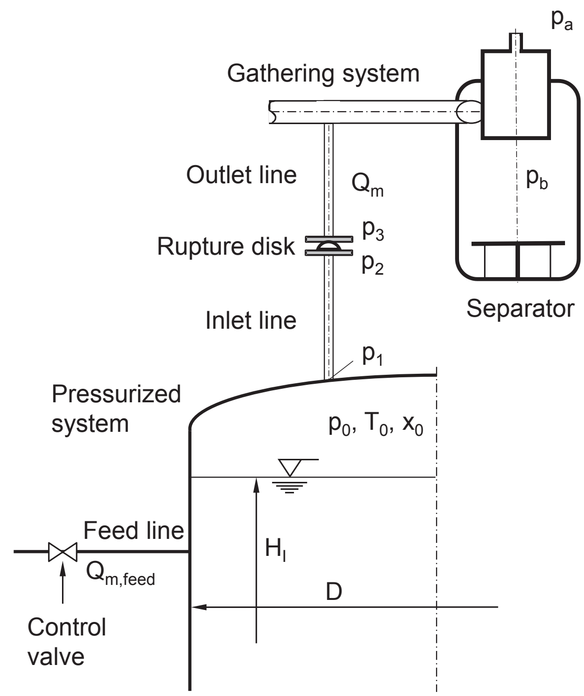

Fig. 2. Industrial rupture disk vent line system.

In the following, all steps are described in detail.

2.1. Risk analysis — definition of the worst case scenario

Reasonably conceivable deviations from normal plant operation shall be identified and evaluated regarding their hazardous risk potential in a Process Hazard Assessment and Safety Evaluation (PHASE) (Barton and Rogers, 1997). Several well established procedures such as HAZOP (Hazard and Operability Study) (Knowlton, 1985), PHA (Preliminary Hazard Analysis) (Department of Defense (1984)), What-if-Analysis or the more quantitative methods (API RP-521, 2014) including Fault-Tree-Analysis (Fussel et al., 1976) and Event-Tree-Analysis (Lees, 1980) are used in practice. These methods are often supplemented by checklists (CCPS, 1985) with several levels of detail. All those procedures provide the means to assess the causes for a pressure increase. These causes can be related to changes in mass and energy transfer to or from the pressurized system, or a deviation from the normal reaction system, which may occur simultaneously or immediately one after another. Most of the causes for an inadmissible overpressure are

Fig. 1. Burst rupture disk - Type IKB (left) and KUB (right), Rembe GmbH, Brilon.