Hydrodynamics and mass transfer characteristics of liquid driven jet ejectors

Cramers, Peter Hendrikus Mechtildis Renier

Summary

In many chemical processes, requiring gas-liquid- (solid) reactors, gas-liquid interfacial mass transfer frequently limits the overall production rate. High shear rates induced by appropriate disperser configurations can enhance mass transfer by generating very small bubbles. Therefore, the efficient dispersion of gases is of considerable importance in many water treatments, petrochemical, biochemical, pharmaceutical and fine chemical and other chemical engineering processes.

The most frequently used gas-liquid contactors are bubble columns, mechanically agitated reactors and trickle bed reactors. During the last decades there has been an increased interest in the development of more efficient and compact gas-liquid contactors (process intensification). In order to improve the mass transfer rates within bubble columns, special internals were proposed such as baffles, perforated screen plates, motionless mixers and various types of gas distributors. The most common used gas distributors are: spargers, perforated plates and porous plates. Recently, various types of venturi's and/or gas-liquid ejectors were proposed as gas distributors. These special types of gas distributors induce very high shear rates, thereby generating very small bubbles and hence improving the gas-liquid interfacial mass transfer rate of the entire system.
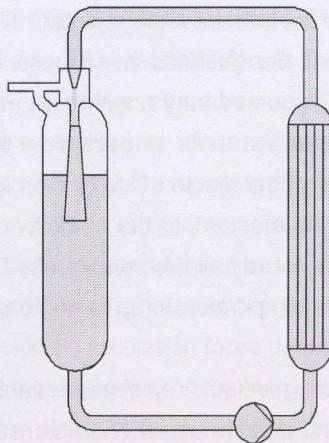
Schematic representation of a commercial Buss Loop Reactor (BLR).

Gas-liquid contactors with ejector type of gas distributors (Loop-Venturi Reactors) have been recommended for processes where gas-liquid interfacial mass transfer is the rate controlling step of the process (Leuteritz, 1976; Nagel et al., 1976; Otake et al., 1981; Ogawa et al., 1983; Radharkrishnan and Mitra, 1984; Rylek and Zahradnik, 1984; Zahradnik et al., 1981; Dutta and Raghavan, 1987; Dirix and van der Wiele, 1990 and Cramers et al., 1992). The most versatile design of a commercial Loop Reactor (BLR) is

claimed to be that developed by Buss AG in Pratteln, Switzerland (Leuteritz, 1976; Malone, 1982). A schematic representation of the BLR is shown in the diagram above.

The Buss Loop Reactor consists of an autoclave, an external forced liquid loop (including centrifugal pump and heat exchanger) and a mixer (gas-liquid ejector) fitted at the top of the autoclave. The reaction mixture, including heterogeneous catalyst, is continuously pumped from the bottom of the autoclave, through the heat exchanger, back into the top of the autoclave through the ejector. In this ejector, through which the reaction suspension travels at a high velocity, the gas is sucked in from the headspace of the autoclave. A zone of high shear mixing is created in the ejector locally, resulting in the formation of small gas bubbles.
The major amount of gas, which has not reacted, disengages in the reaction autoclave and returns to the headspace of the autoclave, where it is re-entrained again into the reaction mixer. The reactor is simple in design and requires no external compression device for dispersing the gas, since the gas phase is sucked in and dispersed by the ejector.

The liquid, which is pumped continuously from the bottom of the autoclave through the external loop, enters the nozzle of the ejector. Due to the reduced cross-sectional area at the outlet of the nozzle, the liquid stream is accelerated. Due to this acceleration, a high velocity jet discharges from the nozzle into the ejector. This high velocity jet causes entrainment (suction) of gas from the gaseous headspace of the autoclave. Inside the reaction mixer the gas phase is dispersed very finely in an intense turbulent field (the so-called mixing shock zone). Thereafter, both phases flow homogeneously through the diffuser and the remaining volume of the ejector. Due to the high velocity inside the ejector, a two-phase jet discharges from the ejector into the autoclave, where further reaction (and gas-liquid separation) takes place. Nearly all the commercial BLR's are slurry reactors and operate at elevated pressures and temperatures (up to 100 barg and 300 °C, respectively).

For the design and scale-up of gas-liquid ejectors, reliable data are required which describe the gas suction rates and mass transfer characteristics as a function of the gas- and liquid physical properties; geometrical design and process related parameters. However, until now a systematic study concerning the influence of the above-mentioned parameters has not been published yet. Therefore, the main objective of this thesis is to get more physical insight in the mechanisms of gas entrainment and gas dispersion within ejectors. Further, in order to obtain reliable design and scale rules/criteria, relations have to be formulated describing the gas entrainment rate and mass transfer rates of gas-liquid ejectors as a function of the gas- and liquid physical properties, the geometrical design parameters and the operating parameters.

Structure of the thesis

This thesis is mainly focused on the ejector as a stand-alone device. In order to understand the physical phenomena occurring in ejectors, first the gas entrainment mechanism of liquid jets has to be studied. Therefore, Chapter 2 deals with the gas entrainment mechanism and rate of high velocity jets. A review is given of previous experimental and theoretical research. Further, the influence of the gas density on the gas entrainment rate and mechanism is studied both experimentally and theoretically. The results of this chapter give a physical explanation on how the gas entrainment rate and mechanism are influenced by the gas density.

Chapter 3 deals with the gas suction rate of ejectors at elevated pressures and on how changes in the gas density affect the gas suction rate. Further the influence of the operating parameters (like the jet velocity and the gas phase pressure difference) and some geometrical parameters are studied. The influence of the liquid physical properties is discussed theoretically and is validated with data from the literature.

The second part of this thesis deals with the mass transfer characteristics of ejectors. Since commercial loop reactors are operated at elevated pressures, Chapter 4 deals with the influence of the gas density on the bubble stability. A relation from the literature is shown to be valid (Levich, 1962) and could be extended to predict the maximum stable bubble size present in an isotropic turbulent flow field. The extended relation is validated using data from the literature. This relation forms the basis for the mass transfer correlations applied in the following chapters. In Chapter 5, the mass transfer characteristics of ejectors are studied in more detail. The influences of geometrical parameters (like the nozzle and the ejector configuration) are studied experimentally. The influence of the gas density is also considered. In this chapter, design relations are presented for designing ejectors, independent of scale. This chapter indicates that each ejector configuration requires its own characteristic relation and that the mass transfer characteristics of ejectors should be studied in more detail. The final chapter (Chapter 6) of this thesis is concerned with the modelling of the mass transfer characteristics of ejectors and on how the effects of the ejector configuration and of operating parameters can be explained theoretically. A model has been developed, which is tested with experimental data. The results show that the model is able to predict the experimental data qualitatively. The main conclusion is that the ejector has to be considered as a "reactor system" of two reactor units in series and that the local phenomena occurring in the mixing shock region should be studied in much more detail.