2. Current State of Knowledge of CO\textsubscript{2} Release in Desalination Distillers

In the following, the ME process configuration, which has been chosen as reference configuration for the present work, is described. Furthermore, an overview of previous work on CO\textsubscript{2} release in desalination distillers is given.

2.1 Description of the Multiple-Effect Distillation Process

Multiple-effect distillation (MED) works on the principle of inducing seawater evaporation and vapour condensation inside a series of cells (effects). A variety of multiple-effect process configurations has been installed. The most common process configuration is shown in Figure 2.1. For modelling the CO\textsubscript{2} release process, this configuration has been chosen as a reference.

The evaporator includes a number of cells working at decreasing temperatures and thus at decreasing pressures from the first to the last cell. Each cell is fitted with a bundle of horizontal tubes. Vapour from the steam turbines of a power plant or a boiler is introduced into the tubes of the first cell. Simultaneously feed water is sprayed or otherwise distributed onto the tube bundle. This trickles by gravity onto the outside of the tubes. The vapour condenses inside the tubes. The condensate is pumped back to the boiler for reuse. The enthalpy of condensation allows the feed water to be preheated to the boiling point on the upper tube rows and then part of it to be evaporated on the lower tube rows. The vapour produced is then fed inside the tubes of the second cell where it is condensed, thus evaporating part of the feed water of this cell on the outside of the tube bundle. This process is repeated from cell to cell.

The vapour produced in the last cell is condensed in a separate heat exchanger called final condenser, which is cooled by the incoming seawater, thus preheating the feed water. The water condensed in each cell goes to the next cell, where some of it flashes at the lower pressure, and finally to the condenser. The distillate is then extracted by means of the distillate pump. The part of the brine that has not been evaporated is fed to the brine pool of the next cell, where some of it flashes at the lower pressure, and is finally discharged from the last cell by the brine-blow down pump. The vacuum in the evaporator is maintained by an ejector system which extracts the non-condensable gases present in the vapour phase.
2. Current State of Knowledge of CO₂ Release in Desalination Distillers

Figure 2.1: Reference ME process configuration [Gla03c]
A thermal vapour compressor is often added to the system to improve its efficiency. At the outlet of the last cell, the vapour produced is partially recompressed in a thermocompressor which is fed by high pressure steam. This vapour mixture can thus be used to heat the first cell again.

2.2 Literature Review

The first investigations into CO\textsubscript{2} release in desalination distillers relied on simple reaction models and sparse experimental data. Only chemical reactions in the brine were considered [Cib78, Wat79]. Mass transfer processes were completely neglected. In practice, these investigations often serve as the basis for the different approaches employed by plant manufacturers and other experts to determine the CO\textsubscript{2} release rates for the dimensioning of the venting rates or for simulation purposes.

CO\textsubscript{2} release and alkaline scale formation, which is linked to the CO\textsubscript{2} release through chemical reactions, were investigated experimentally. Shams El Din and Mohammed [Sha94] studied the chemistry of alkaline scale formation in industrial MSF distillers by extracting and analyzing brine samples from the water boxes and flash chambers. Moore et al. [Moo95] carried out corresponding investigations into CO\textsubscript{2} release. Shams El Din and Mohammed [Sha88, Sha89] as well as Al-Sulami and Hodgkiess [Al-S97] performed laboratory studies on the mechanism and rates of chemical reactions in aqueous bicarbonate solutions with respect to alkaline scale formation.

Lukin and Kalashnik [Luk82] and later Seifert [Sei89] developed the first physical models that allowed the calculation of the CO\textsubscript{2} release rates in individual MSF distiller stages. The models are based on the assumption that mass transfer phenomena in the brine rather than the reaction kinetics control the desorption process. Chemical reaction kinetics were scarcely investigated.

Rigorous electrolyte thermodynamics were applied to the simulation of CO\textsubscript{2} release in MSF distillers by Watzdorf and Marquardt [Wat97]. The brine is considered as a multi-component electrolyte system of varying complexity. Scale formation and CO\textsubscript{2} release are predicted assuming equilibrium conditions. The proper description of the electrolyte system and of the equilibrium state in a thermodynamic model is considered to serve as a limiting case or as a prerequisite of any rate-based model.

Glade [Gla99a, Gla01a] found that the above mentioned investigations did not combine the mass transfer processes with the effects coming from the chemical reactions. Furthermore, the reaction kinetics involved in the release process of
CO₂ as well as in the precipitation processes of CaCO₃ and Mg(OH)₂, e.g. the reaction mechanisms and the rate constants of the rate-determining steps in the mechanisms, have not been adequately described in desalination literature. Glade proposed to treat the release of CO₂ in MSF distillers as a problem of chemical desorption. The coupling of mass transfer and chemical reaction kinetics was investigated and the rate-controlling steps in the CO₂ release process were determined. A model has been developed that describes the reactions and mass transfer processes in the CO₂ system of the brine as well as the CO₂ release in MSF distillers. Included is the flow path of brine through the condensers, the brine heater and the flash chambers. In recycle distillers, the deaerator was also considered.

The simulation results of the model were experimentally verified [Gla99b, Gla01a]. For measuring the CO₂ release, a new experimental approach was applied: For the first time, the CO₂ flow rates in the venting lines of individual stages of MSF distillers were determined. The CO₂ concentrations were measured on-line and continuously in the parallel vents of the MSF distillers by means of a mass spectrometer. At the same time the total vent flow rates, the temperature and the pressure of the vents were measured. The measurements were carried out at two MSF recycle distillers in the Arabian Gulf with a wide range of operating conditions. The model predicts the actual desorption profiles very well. The mean difference between model and experiment was 15 %, the maximum difference was 30 % [Gla99b, Gla01a].

The previous work of Glade [Gla99a, Gla99b, Gla01a, Gla02] on modelling and simulation of CO₂ release in MSF distillers serves as a very useful basis for the present investigation, since the main concept and the methodology applied to the prediction of CO₂ release in MSF distillers can be transferred to the CO₂ release in ME distillers. The single steps in modelling and simulation, however, have to be performed once again for the MED system, since there are decisive differences between MSF and MED systems regarding evaporation mechanisms, hydrodynamics, operating temperatures and pressures, concentrations, brine residence times and process configurations. For example, the phase interface areas and the mass transfer coefficients are different in MSF and ME distillers. Compared to MSF distillers, the desorption of CO₂ in ME distillers may occur in different reaction regimes depending on the relative rates of the chemical reactions and the mass transfer processes.