EFFECTIVENESS–NTU METHOD FOR
DESIGN OF PACKED BED LIQUID
DESICCANT DEHUMIDIFIERS

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This paper describes the application of the Effectiveness (ε)-NTU method of heat exchanger design, a well established and relatively simple design procedure, to packed beds where simultaneous heat and mass transfer processes occur. The method, also used for cooling tower design, is extended easily to packed bed liquid desiccant dehumidifiers. Computations indicate that at the operating ranges normally encountered in dehumidifiers, the ε-NTU method yields results that are in consonance with those obtained using more rigorous and well established but time consuming methods. The model also compares satisfactorily with the limited experimental data available.

INTRODUCTION

Dehumidification of gases is an important operation not only in industry, but also in the comfort conditioning of living space. Traditionally, air has generally been dehumidified by cooling it below its dew point using the conventional vapour compression cycle. This is highly energy intensive and other methods such as contacting the gas with desiccant materials are gaining importance. The desiccants can be either solid or liquid, but studies have shown (Factor and Grossman1) that liquid desiccants have flexibility in operation and this makes them more attractive than solid desiccants. In general, when a gas is brought into contact with a liquid in which it is essentially insoluble, interphase transport of mass and energy can be expected to take place. The terms 'humidification' and 'dehumidification' operations denote change in the vapour content of the gas; but in practice temperature changes also generally occur in both the gas and liquid phases. The matter transferred between the phases is the substance comprising the liquid phase which either vaporizes or condenses (Treybal2).

There are many models and methods available in the literature to estimate the outlet conditions of the air and liquid in packed bed dehumidifiers. Factor and Grossman1 developed a finite difference model which, following Olander’s3 approach in the design of direct contact cooler-condensers, neglected the resistance to heat transfer on the liquid side, by assuming the interfacial temperature to be the same as the bulk liquid temperature. Gandhidasan et al.4, following the rigorous treatment of Treybal5, proposed a finite difference model which, while it included mass transfer resistances, neglected heat transfer resistances on the liquid side. Sherwood and Pigford6, neglecting heat and mass transfer resistances in the liquid side as well as any change in liquid flow rate (little evaporation), developed a model to predict both air temperature and humidity profiles in the column. In the above models, the finite difference techniques employed require a very large number of segments through the column to obtain reasonably acceptable results. Moreover, being iterative procedures, the use of a computer is mandatory.

The effectiveness (ε)-NTU method, originally proposed by Nusselt and developed extensively by Kays and London7, is a well established technique in the rating problem of heat exchangers. The principal advantage of this method is that iterative or trial and error calculations can be minimised. Stevens et al.8 introduced an effectiveness model for liquid desiccant heat/mass exchangers which is based on a similar model developed by Braun9 for cooling towers. The Stevens et al. model uses a definition of NTU based on the gas mass velocity, 'G'. Jaber and Webb10 have shown recently that this approach, used by most previous investigators in cooling tower design, may fail when the minimum flow capacity is the liquid. While this does not occur frequently in cooling tower operation, it is normal in liquid desiccant dehumidifiers. In cooling towers and dehumidifiers, simultaneous heat and mass transfer take place, unlike heat exchangers where only sensible heat transfer takes place. In heat exchangers, the driving force is the temperature difference between the fluids alone. On the other hand, in cooling towers the mass transfer also contributes to the enthalpy transfer, and the driving force in addition to the temperature difference includes moisture content difference. The complexity of the equations can be reduced by using the moist air enthalpy potential proposed by Merkel11. The analysis of this complicated process has been described by Webb12. The earliest attempt to apply the ε-NTU method to cooling towers was by Moffatt13. However, this and other ε-NTU models, as pointed out by Jaber and Webb10, use definitions of NTU that are inconsistent. This paper describes the application of the ε-NTU method to packed bed liquid desiccant dehumidifiers using the consistent definition of NTU of Jaber and Webb10.

MODEL DESCRIPTION

The driving force in simultaneous heat and mass transfer processes is the enthalpy difference (see appendix 1). This approach was proposed by Merkel11 with reference to cooling towers. The assumptions for this approach are:

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