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Regression analysis of a curved vane demister with Taguchi based optimization

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HIGHLIGHTS

- A Taguchi coupled CFD analysis used L25 OA to identify optimal vane shape.
- Friction factor, droplet separation efficiency was chosen as objective functions.
- Responses from CFD fed to Minitab and ANOVA estimates were carried out.
- Parameters that influence the objective functions were identified.
- Regression analysis was done to develop correlations for objective functions.

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ABSTRACT

Regression analysis was carried out using least squares method to develop correlations for the objective functions: friction factor (f) and droplet separation efficiency (η) of curved vane demisters used in seawater desalination. A Taguchi coupled CFD analysis performed earlier by the authors, to select the optimal geometrical parameters for a curved vane demister, was the baseline for this work. Responses of the chosen objective functions from the CFD analysis were fed to the statistical tool Minitab. ANOVA estimates were carried out for identifying the significant factors that control f, η and ranked. Linear model analysis was carried out for the signal-to-noise (S/N) ratios with '*smaller the better*' approach for f and '*larger the better*' approach for η. The R-square value for the correlation developed for f and η was found to be 98% and 87.9% respectively. The ranking of the parameters correlates very well with the numerical estimates. The factors like '*vane pitch*' and '*hook height above the vane*' were identified to have most significant influence when compared to other parameters.

1. Introduction

Desalination, a process of producing water vapor from saline water and condensing it, is widely being adopted for the generation of fresh water, for several day-to-day human usage and industrial applications, with varying levels of quality and quantity. Maintaining salinity levels in the generated fresh water thus produced, needs the removal of entrained water droplets from the water vapor generated. Several devices like packages, filters, cyclones, baffles, vanes and wire mesh were tested by several researchers as '*demisters*' to remove the entrained saline water droplets. Choice of selection among these devices depends on various factors such as mist or droplet size, flow rate, temperature, and other operating conditions.

In mist eliminators, the wave or vane profiles were typically designed and the vapor, droplet mixture flow was made to pass through a narrow path between pairs of these shaped plates. The liquid droplets, due to their greater inertia, cannot make the sharp turns and as a result, were thrown towards the plate surfaces, impinges and briefly held on the plates. As more droplets get collected, they accumulate and grow in size, run down and fall from the unit. Thus the entrained saline liquid was removed from the vapor flow effectively, predominantly done by inertial impingement.

1.1. Separation and re-entrainment of droplets

The liquid droplet gets separated effectively when the gravity force was larger than the drag force of the up flowing gas stream. Few of

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these drops get re-entrained into the stream at higher vapor velocities, which can be reduced or prevented by introducing hooks at specific locations in the vanes. The presence of the hook promotes separation of fine droplets but results in increased pressure drop. In order to achieve a tradeoff between the separation efficiency and pressure drop for different vane demister geometries, and to choose an optimal combination of demister geometrical parameters, numerical studies were carried out.

1.2. Computational studies in vane demisters

Several computational studies have been carried out by several researchers in the past, to find the influence of these parameters on the flow through vane demisters. Experimental and numerical studies have been reported discussing the performance of various demisters by estimating the droplet separation efficiency and pressure drop across the vane, as used in various industrial applications [1–6]. Developing an optimal curved vane demister design which possesses a smaller pressure drop and highest droplet separation efficiency was critical. This would enhance the productivity and efficiency of the present desalination plants used for fresh water generation.

1.3. Optimization coupled CFD analysis of demisters

Research work reported in the open literature, where an optimization tool was coupled with other virtual validation tools, to design and analyze demisters was very limited. Narimani and Shahhosseini [7] studied and investigated the efficiency of vane type mist eliminators using computational fluid dynamics (CFD), where STD k–ε model was used, for different inlet gas velocities. The authors obtained a prediction model of the separation efficiency for the optimized vane geometries using response surface methodology (RSM). The simulation results showed that there was a conceivable dependency of separation efficiency on the gas velocity and geometrical parameters of vanes. The optimal values of these parameters were determined in order to achieve the maximum separation efficiency. Similar study using RSM was conducted on demister vanes by Zhao et al. [8]. The performance of plain wave plate separators has been assessed in terms of the collection efficiency, pressure drop across the separator and its size by Wilkinson [9]. Experimental data were correlated using empirical descriptions of the wave plate operation based on simple theory and existing correlations for duct flows. Using these relationships, a method to optimize designs of plain wave plate separator in terms of pressure drop has been devised and demonstrated.

Venkatesan et al. [10] designed a curved vane demister using a combined CFD and optimization approach. Taguchi analysis was carried out with the help of an optimization tool Minitab, where the geometrical parameters were fed as input factors at chosen levels and vane design parameters were obtained. Flow of water vapor and water droplets through these vanes thus designed, were analyzed numerically using a CFD solver Ansys Fluent to estimate the pressure drop and droplet separation efficiency. Optimal designs of the curved vane demisters with hook were recommended, having the high droplet separation efficiency along with a low pressure drop.

Though an optimal design was identified using optimization coupled CFD analysis, for the chosen design, the performance of the demister with geometric parameters that are different from the ones tested is still not known. To estimate the performance of those designs, one needs to resort to the same analytical methodology again. Hence the present work aims at developing correlations using regression analysis for the responses obtained from the numerical analysis carried out by the authors earlier. Correlations were developed for the objective functions f and η by using the statistical tool Mini Tab.

2. Selection of optimal demister

A brief summary of the work reported by Venkatesan et al. [10] is stated here for the purpose of maintaining continuity in the present discussion. A baseline model of the curved vane demister with hook was identified, as shown in Fig. 1 along with the key dimensions. The thickness of the plate used for the design of the curved vane was 2 mm and the overall vane height in the stream-wise direction was 100 mm. The quality or the performance of the curved vane demister was assessed by its ability in removing the entrained water droplets from the flashed water vapor.

Taguchi method has been successfully used by various researchers to many product development situations [11,12]. In Taguchi method, the experiments were designed first and later provide an optimized design having higher performance index with high quality and at a lower overall cost. Venkatesan et al. [10] employed Taguchi coupled CFD analysis for the selection of an optimal curved vane demister. For the purpose of analyzing the curved vane geometry using Taguchi method, two levels of variations on the lower side and two on the higher side were chosen for each key geometry dimensions, as shown in Table 1. The important geometry parameters chosen are shown in Fig. 2: vane depth (D1), hook-to-center distance (D2), hook height above vane (D3), hook length (D4), hook inclination angle (θ) and vane pitch (P). The values for the baseline model used are highlighted in column named as 'Level 3'.

Minitab software [13] was used for the optimization estimates and for the chosen 6 parameters with 5 levels of variations; a L_{25} OA (orthogonal array with 25 designs) was selected, as in Table 2. Geometry shapes of the 25 number of curved vane demisters developed based on the inputs from the OA and used are shown in Fig. 3 (refer

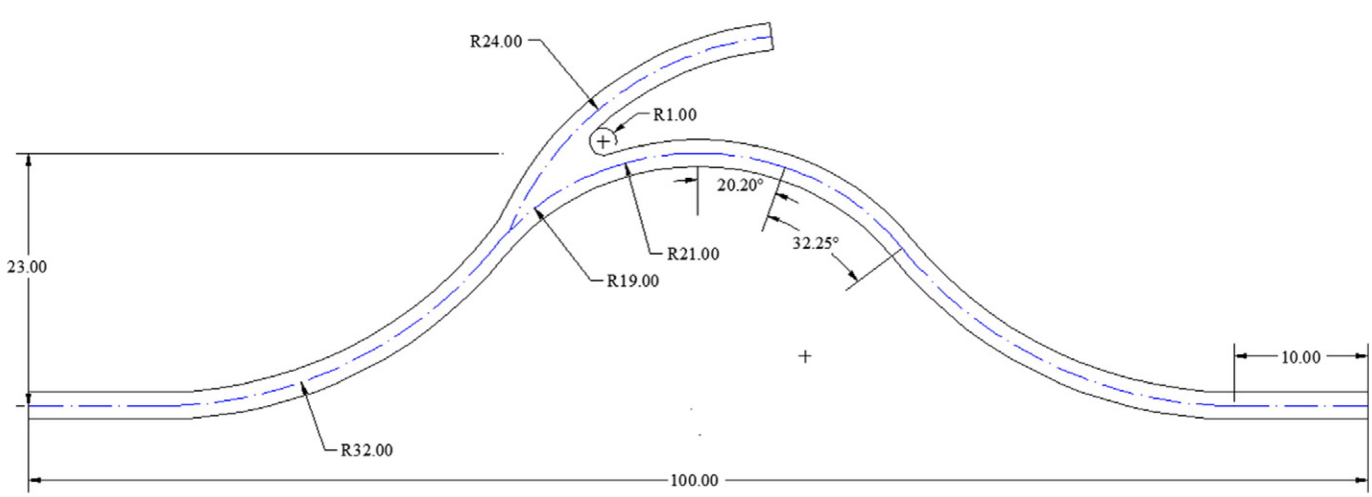

Fig. 1. Base line model of the curved vane demister, Venkatesan et al. [10].