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EXERGY LOSSES RELATION WITH DRIVING FORCES IN DISTILLATION COLUMN

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ABSTRACT

Present investigation involves computation of the exergy losses of the whole column by considering the factors of irreversibility of distillation columns, and comparison of their impact. This included combining the relations of energy-exergy balance with design relations, with impact of various parameters (such as design and operational) on exergy losses of distillation columns. The difference between present method and those carried out elsewhere is the ability to compute exergy losses by applying separate types of irreversibility in the distillation column. This was meant to show comparisons of the sources of irreversibility. Results suggest that the driving forces of mass transfer among other parameters have the most effect on these losses. By the same token reducing these forces can reduce the rate of exgery losses. The paper finally recommends effective methods for reducing the rate of exergy losses in industries in general and the petro-chemicals in particular.

Keywords: Exergy losses, Driving forces, Distillation column

1. Introduction

Limitation of 'non-renewable' fossil energy sources on one hand and potential environmental consequences (greenhouse effects) on the other have caused serious industrial management challenges. This necessitates serious considerations for economy in general and industry in particular. For these reasons attempts is being made here to establish systematic techniques in order to promote efficiency in the process. One of the methods to achieve this is to reduce the exergy losses. Distillation is a process which consumes a considerable amount of energy. Considering the broad application of distillation columns in industries, especially oil and petrochemical, it is necessary to optimize the outcome. To make temperature gradient in distillation column, which is necessary for the separation of elements, needs energy. However, energy balance can provide useful information about the state of the system so far as the losses from the plant body and incomplete combustion are concerned. However, it doesn't display any difference between types of energy and doesn't consider the losses due to decrease of energy quality.By definition, exergy is referred to as the maximum shaft or electrical work in a reversible process when the system reaches the ambient conditions. Exergy analysis makes it possible to provide methods for thermodynamic development [1]. Bonsjakovic was one of the early leaders in applying the exergy analysis to processes in his fight against irreversibility [2]. Kotas has generally studied the exergy balance and irreversibility sources in the distillation columns [3]. R. J. Zemp S.H.B. de Faria and M.de L. Oliveira Maia, investigated the profile of driving forces and determined the exergy losses profile of the distillation columns[4]. E. Sauar, G. Siragusa and B. Andresen studied and compared the efficiency of binary distillation columns in two ideal thermodynamic cases[5]. R.J. Zemp and M.de L. Oliveira Maia provided thermodynamic analysis of distillation columns to find the best condition of feed[6]. Yunus Cerci studied the distillation column of salt- contained water so that the minimum work needed for these columns can be provided[7]. G. de Koeijer and R. Rivero studied the entropy production and exergy losses in experimental distillation columns[8]. A. S.Tijani, N. Ramazan, W.Witt, conducted a thermoeconomic study to compute the highest economical efficiency of distillation columns. In this study, the exergy and entropy balance have been provided for distillation column and the thermodynamic efficiency of distillation columns investigated by integrative the thermodynamics and economical relations.[9]. A. C. B. Araújo, L. G. S. Vasconcelos, M. F. Fossy, and R. P. Brito provided the exergy and economical analysis for industrial distillation columns. In their study, the effect of the temperature difference in reboiler, on various parameters was investigated [10]. I. Dincer and M.A.Rosen analysed the distillation column for petroleum refinement[11]. A.N.Anozie, F.N.Osuolate, A.S.Osunleke studied the effects of key process parameters on the stage-exergy rate diagrams in binary distillation columns[12].

In present research the relations of the energy- exergy and the design relations have been combined, so that it can be possible to include the effect of various parameters such as design and operational parameters on the exergy losses of distillation column. Another difference between this work and the previous works is the ability to compute the exergy losses caused by different kinds of irreversibilities in the distillation columns separately. Thus, the source of irreversibility will be comparable.

2. Exergy Analysis in Distillation Columns

The common method which is used to analysis the distillation columns is to apply the exergy balance around the column, in which the exergy losses can be computed by the difference of input and output exergies[3]. Another method that seems to be effective to understand the concepts and by which better interpretations can be made, is to recognize the source of irreversibility and to calculate the exergy losses of each one, and then to compute the total losses of column by the sum of all compared amounts. The main source of irreversibility in distillation column are: the mass transfer between phases, heat transfer in reboiler, heat transfer in condenser, heat transfer of the flows inside the column, heat losses through the external surface of the column, friction of fluids and conduction heat transfer along the column.

2.1. Exergy Losses Caused by Mass Transfer

The exergy losses caused by the mass transfer can be stated as the exergy difference of input and output flows resulted from the concentration changes. This can be computed by the relations 1 and 2.

$$EL_{\Delta C} = EX_F - \left(EX_D + EX_B\right) \tag{1}$$

$$EL_{\Delta C} = RT_{\circ}\left[\ell n\left(\pi_{i=1}^{n}\frac{\left(xi_D^{\ niD}.xi_B^{\ niB}\right)}{\left(xi_F^{\ niF}\right)}\right)\right] \tag{2}$$

2.2. Condenser Exergy Losses

The exergy losses caused by heat transfer in the condenser can be computed through relation 3.

$$EL_{cond} = Q_C\left(1-\frac{T_{\circ}}{T_D}\right) \tag{3}$$

Q_c is the rate of heat transfer inside the condenser.

2.3. Reboiler Exergy Losses

Exergy losses in reboiler can obtained from equation 4:

$$EL_{reb} = Q_B\left(1-\frac{T_{\circ}}{T_B}\right) \tag{4}$$

Q_B is the rate of heat transfer in the reboiler.

2.4. Exergy Losses Caused by Flows Heat Transfer

There are complex flows inside the column which transfer heat and mass simultaneously. The phenomena of mass transfer and computation of exergy losses caused it, were studied in section 2.1.With regard to the heat transfer of flows inside the column, due to the complexity of the process and continues simultaneity of vaporization and condensation of inside flows of the column, computing the rate of heat transfer becomes so complicated. To avoid this complexity, the model in figure (1) is considered as a hypothetical model.

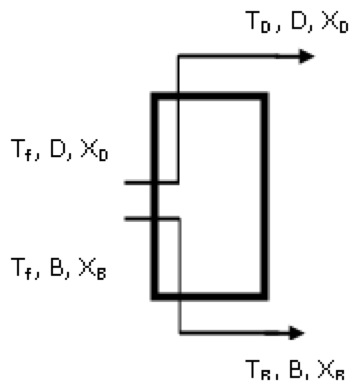

Figure1. Model for calculation of heat transfer in distillation column

Since exergy is a state function, the above model doesn't make any problems in computation of exergy losses. then:

$$EL_{\Delta T}=EL_{\Delta TB}+EL_{\Delta TD} \tag{5}$$

$$EL_{\Delta TB}=\Delta h_{F-B}\left(1-\frac{T_\circ}{\overline{T}_{F,B}}\right) \quad \& \quad EL_{\Delta TD}=\Delta h_{F-D}\left(1-\frac{T_\circ}{\overline{T}_{F,D}}\right) \tag{6}$$

Log mean temperature can be calculated relation 7:

$$\overline{T}=\frac{T-T_{Feed}}{\ell n\, T/T_{Feed}} \tag{7}$$

Δh_{F-B} and Δh_{F-D}, are the enthalpy difference between feed and products that can be calculated by relations (8) and (9):

$$\Delta h_{F-B}=h_B-h_F=B\sum_{i=1}^{n}xi_B hi_B-F\sum_{i=1}^{n}xi_B-hi_B \tag{8}$$

$$\Delta h_{F-D}=h_D-h_F=D\sum_{i=1}^{n}xi_D hi_D-F\sum_{i=1}^{n}xi_F-hi_F \tag{9}$$

2.5. Exergy Losses Caused Heat Losses

The temperature difference between the surface of the column and the environment causes an undesirable heat transfer between them. This losses can be reduced by insulating the surface. The rate of heat transfer from the surface of the column can be computed through dividing the temperature gradient between inside and outside of the column by the total heat resistance:

$$q_{loss}=\frac{\Delta T_{overall}}{\sum R_{th}} \tag{10}$$

By substituting equivalent resistance, it can be written:

$$q_{loss} = \frac{T_i - T_\circ}{\frac{\ell n \, r_1 / r_i}{2k_t \pi L} + \frac{\ell n \frac{r_\circ}{r_1}}{2k_i \pi L} + \frac{1}{2h\pi L}} \tag{11}$$

Having the rate of heat transfer from the body of the column, the exergy losses can be determined:

$$EL_{Qloss} = Q_{loss}\left(1 - \frac{T_\circ}{T_{av}}\right) \tag{12}$$

In relation (12) the parameter "T" is the temperature of each ideal stage which must be computed by determining the temperature of each tray. In other words, the quantity of Q_{loss} for an ideal stage is computed, then the quantity of el_{Qloss} for the losses from the surface in each tray is determined:

$$EL_{Qloss} = \tag{13}$$

The temperature of each stage can be estimated by knowing the composition, applying equilibrium data, Rault law and Antoin equation. Finally, to compute the exergy losses from the whole column it can be written:

$$EL_{\Delta C} \quad EL_{reb} \quad EL_{Qloss} + EL_{cond} \quad EL_{\Delta TD} \quad EL_{\Delta TB} \quad EL_{total} \tag{14}$$

$$EL_{total} = \Delta h_{F-D}\left(1 - \frac{T_\circ}{\overline{T}_{F,D}}\right) + \Delta h_{F-B}\left(1 - \frac{T_\circ}{\overline{T}_{F,B}}\right) + RT_\circ\left[\ell n\left(\pi_{i=1}^{n} \frac{\left(xi_D^{\ niD} . xi_B^{\ niB}\right)}{\left(xi_F^{\ niF}\right)}\right)\right] +$$

$$+ Q_B\left(1 - \frac{T_\circ}{T_B}\right) + Q_C\left(1 - \frac{T_\circ}{T_D}\right) + Q_{loss}\left(1 - \frac{T_\circ}{T_{av}}\right) \tag{15}$$

The first term on the right side of the equation (15) indicates the exergy losses caused by mass transfer. Naturally the more rate of separation increase the more this number will increase. The second and third terms on the right side indicate that the exergy losses are caused by heat transfer inside the condenser and reboiler. As the rate of heat transfer and the temperature of condenser and reboiler increase, this losses will also increase. The third and fourth terms on the right side of equation (19) indicate exergy losses caused by heat transfer of the flows inside the column. The more rate of separation and mean temperature at the upper and lower parts of the column increase, the more these losses increase. The last term is the exergy losses from the surface of the column which increase with the rising of the temperature of stages or the rate of heat transfer from the column.

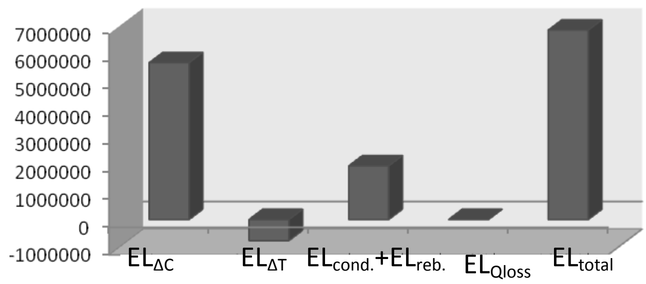

Figure2. Exergy losses distribution due to irreversibilities in distillation column

3. A Case Study

Methanol distillation unit was considered as a case study and the impact of various parameters on exergy losses was studied. The overall result is illusterated in figure (2). As shown, irreversibilities caused by mass and heat transfer in the boiler and condenser have maximum exergy losses. These two factors are caused by the driving forces of mass and heat transfer which are concentration and temperature difference, respectively in the system. For more accurate studies, exergy losses were computed once by changing feed concentration at constant temperature and once again by changing feed temperature at constant concentration, and the results of this study have been illustrated in figures (3) and (4).

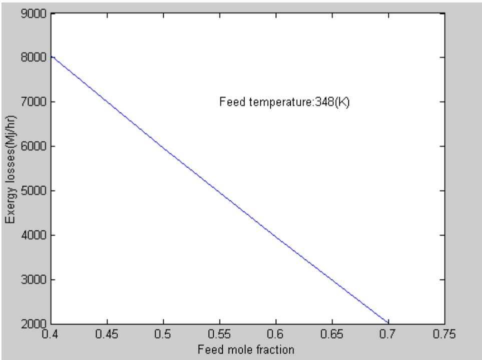

Figure 3. Exergy losses vs. feed mole fraction

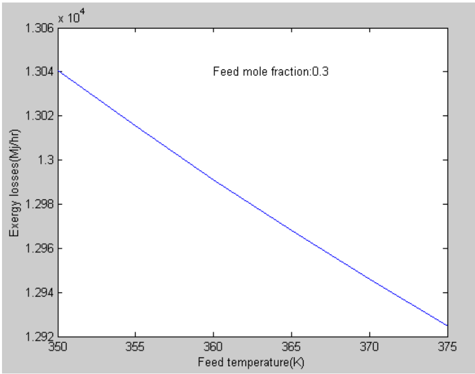

Figure4. Exergy losses vs. feed temperature

As shown, the effect of changes in feed concentration is more than that of changes in feed temperature.

4. Results

Results suggest that the driving forces of mass transfer among other parameters have the most effect on exergy losses. Therefore if the gradient of concentration in column have been reduced, it can be declined the exergy losses. One method for reduction driving force of mass transfer is recycling a part of products to feed of column. Figure (5) shows this method.

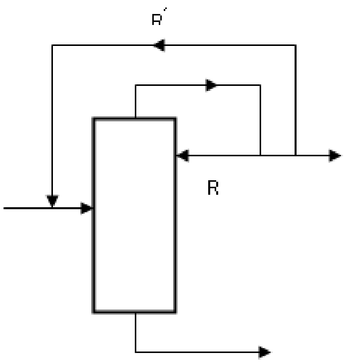

Figure5. Product recycling to feed for reduce of exergy losses

Figure (6) shows the effect of mentioned method on exergy losses in distillation column of the case study. As can be observed any increase in the products recycling will have a corresponding decrease in the exergetic losses. But it should not be forgotten that this method lead to reduce the production. Consequently, a thorough analysis is needed to select an economically feasible method to obtain optimum parameters.

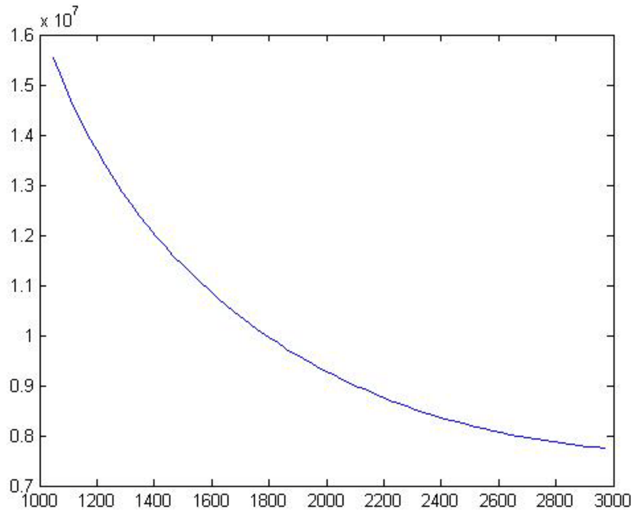

Figure6. Product recycling effect on exergy losses in distillation column

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