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# Heat Transfer Enhancement and Optimization of Lean/Rich Solvent Cross Exchanger for Amine Scrubbing

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#### Abstract

The lean/rich amine cross exchanger is one of the cost centers in the amine scrubbing process, and accounts for 20-30% of the capital cost. To minimize the cross exchanger cost, shortcut methods that determine optimum LMTD and fluid velocity were developed. The optimum LMTD is a function of heat transfer coefficient, temperature change and the capital cost of heat exchanger. A greater LMTD should be used to prevent excessive capital cost when the number of heat transfer units (NTU) is large and the heat transfer coefficient is small. The heat transfer performance can be enhanced by increasing pressure drop and reducing solvent viscosity. The corrugation angle is the primary design geometry for plate-and-frame exchanger (PHE). Based on the empirical correlations for PHE, the heat transfer coefficient at  $60^{\circ}$  is almost double that at  $30^{\circ}$ ; however, the pressure drop at a large corrugation angle is also greater. The dependence of the pressure drop per unit length on the heat transfer coefficient is 0.35-0.40, which implies that the heat transfer coefficient will increase 30% by doubling the pressure drop per unit length. The cost associated with the optimization of the cross exchanger has been developed as a function of the fluid velocity, the physical properties, the exponents of the empirical correlations and the pricing parameters. The optimum velocity is independent of the solvent rate, the temperature change of the cross exchanger, and the cross exchanger LMTD. To stay at optimum fluid velocity, the plate number needs to increase as the solvent rate increases while the plate length will increase as the NTU increases. Viscous solvent will result in a lower optimum velocity since it causes higher pressure drop. Typical optimum fluid velocity is at 0.32-0.42 m/s for 8 m PZ. It is worthwhile to utilize higher fluid velocity and pressure drop when the heat transfer can be effectively enhanced by turbulence.

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#### 1. Introduction

In the amine scrubbing process, the lean/rich amine cross exchanger is used to recover the sensible heat from the hot lean solvent. The cross exchanger heat duty is 3 to 5 times the actual reboiler duty input. Since a large amount of heat is transferred, the capital cost of the cross exchanger is one of the cost centers, accounting for 20–30% of capital cost [1].

To reduce the cross exchanger cost, the most important design parameter, the log mean temperature difference (LMTD), should be optimized. Furthermore, the heat transfer performance can be enhanced by increasing the pressure drop and using a less viscous solvent. This paper aims at investigating the pressure drop and viscosity effect on the cross exchanger performance and reducing the capital cost by providing an optimum design. The plate-and-frame exchanger will be considered to be the type used for the cross exchanger. Mechanical and structure design will not be in the scope of this work.

| Aheat exchanger areaCCOEcost of electricityCrconstant in pressure drop correlationCNuconstant in heat transfer correlationCyheat capacityCPECpurchased equipment costDeequivalent diameter (=2\delta)ffanning friction factorhheat transfer coefficientkthermal conductivityLTtotal length of flow pathNuNusselt number (= $hD_c/k$ )mexponent of Renexponent of Prpexponent in pressure drop correlationQexchanger heat dutyReReynolds number (= $\rho uD_e/\mu$ )Tamstaam temperatureTrebreboiler temperatureVsolvent volume flow rateufluid velocityWrtotal heat transfer coefficientVsolvent volume flow rateufluid velocityWrtotal width of platesGreek- $a$ capital cost scaling factor $A$ capital cost scaling factor $A$ total pressure drop $APL_L$ pressure drop per unit length $AT_{LM}$ log mean temperature difference $A$ plate spacing $p$ pump efficiency   | Nomenclature     |                                       |  |
|---|------------------|---------------------------------------|--|
| $C_{COE}$ cost of electricity $C_r$ constant in pressure drop correlation $C_{Nu}$ constant in heat transfer correlation $C_{Nu}$ constant in heat transfer correlation $C_p$ heat capacity $C_{PEC}$ purchased equipment cost $D_e$ equivalent diameter (=28)ffanning friction factorhheat transfer coefficientkthermal conductivity $L_r$ total length of flow pathNuNuselt number (=hD_k/k)mexponent of Rerinsolvent mass flow ratenexponent of Prpexponent in pressure drop correlationQexchanger heat dutyReReynolds number (= $\rho u D_e/\mu$ )T_sunsteam temperatureUoverall heat transfer coefficientÝsolvent volume flow rateufluid velocityWPwidth of patesGreekcapital cost caling factorAcapital cost caling factorAPtotal pressure dropAP/Lpressure dropAP/Lig mean temperature fifterence $A$ capital cost caling factor $AP$ total pressure dropAP/Lig mean temperature fifterence $A$ capital cost caling factor $AP$ total pressure drop $AP/L$ ig mean temperature difference $A$ ig mean temperature difference $A$ pate spacing $\eta_P$ pump efficiency   | , onen           |                                       |  |
| Crconstant in pressure drop correlationC <sub>Nu</sub> constant in heat transfer correlationC <sub>p</sub> heat capacityC <sub>PEC</sub> purchased equipment costD <sub>e</sub> equivalent diameter (=2δ)ffanning friction factorhheat transfer coefficientkthermal conductivityLrtotal length of flow pathNuNusselt number (=hD <sub>e</sub> /k)mexponent of Rensolvent mass flow ratenexponent of Prpexponent in pressure drop correlationQexchanger heat dutyReReynolds number (=puD <sub>e</sub> /µ)Twosteam temperatureUoverall heat transfer coefficientVsolvent volume flow rateufluid velocityWpwidth of platesGreekcapital cost scaling factorβcapital cost scaling factorβcapital cost scaling factorβpressure dropAPL_Mlog mean temperature differenceβtotal pressure dropAPL_Mlog mean temperature differenceβcapital cost scaling factorβcapital cost scaling factorβcapital cost scaling factorβplate spacingη <sub>P</sub> pump efficienceβplate spacingη <sub>P</sub> pump efficienceβplate spacingη <sub>P</sub> pump efficienceβplate spacingη <sub>P</sub> pump efficienceβplate spacing <th>А</th> <th>heat exchanger area</th> | А                | heat exchanger area                   |  |
| $C_{Nu}$ constant in heat transfer correlation $C_{Pu}$ heat capacity $C_{PEC}$ purchased equipment cost $D_{e}$ equivalent diameter (=28)ffanning friction factorhheat transfer coefficientkthermal conductivity $L_{T}$ total length of flow pathNuNusselt number (= $D_{e}/k$ )mexponent of Reinsolvent mass flow ratenexponent of Prpexponent in pressure drop correlationQexchanger heat dutyReReynolds number (= $p_{e}/\mu$ )Tasmstam temperatureT <sub>reb</sub> reboiler temperatureUoverall heat transfer coefficientÝsolvent volume flow rateufluid velocityWpwidth of platesGreckcapital cost scaling factor $\beta$ capital cost scaling factor $\beta$ capital cost scaling factor $A$ total pressure drop $AP/L_{L}$ log mean temperature difference $\delta$ plate spacing $\eta_p$ punp efficiency   | CCOE             | cost of electricity                   |  |
| Cp      heat capacity        CpEC      purchased equipment cost        De      equivalent diameter (=28)        f      fanning friction factor        h      heat transfer coefficient        k      thermal conductivity        Lr      total length of flow path        Nu      Nusselt number (=hD <sub>c</sub> /k)        m      exponent of Re        rin      solvent mass flow rate        n      exponent of Pr        p      exponent of Pr        p      exponent of Pr        p      exponent are drop correlation        Q      exchanger heat duty        Re      Reynolds number (= $\rho uD_e/\mu$ )        Tsun      steam temperature        Treb      reboiler temperature        U      overall heat transfer coefficient $\dot{Y}$ width of each plate        WT      total width of plates        Greek  | $C_{\rm f}$      | constant in pressure drop correlation |  |
| C <sub>PEC</sub> purchased equipment cost $D_e$ equivalent diameter (=28)        f      fanning friction factor        h      heat transfer coefficient        k      thermal conductivity        Lr      total length of flow path        Nu      Nusselt number (=hDe/k)        m      exponent of Re        rin      solvent mass flow rate        n      exponent of Pr        p      exponent in pressure drop correlation        Q      exchanger heat duty        Re      Reynolds number (=puDe/μ)        T <sub>stm</sub> steam temperature        T <sub>reb</sub> reboiler temperature        U      overall heat transfer coefficient $\dot{V}$ solvent volume flow rate        u      fluid velocity        Wp      width of each plate        WT      total width of plates        Greek  | C <sub>Nu</sub>  | constant in heat transfer correlation |  |
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| hheat transfer coefficientkthermal conductivityLTtotal length of flow pathNuNusselt number (=hDe/k)mexponent of Rerinsolvent mass flow ratenexponent of Prpexponent in pressure drop correlationQexchanger heat dutyReReynolds number (=puDe/µ)Tamsteam temperatureTrebreboiler temperatureVoverall heat transfer coefficientÝsolvent volume flow rateufluid velocityWpwidth of each plateGreekcapital cost scaling factorΔPcapital cost scaling factorΔP/Lpressure dropΔP/Lgo mean temperature differenceδplate spacingηµppunp efficiency  | De               | equivalent diameter (= $2\delta$ )    |  |
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| pexponent in pressure drop correlationQexchanger heat dutyReReynolds number (= $\rho$ uDe/ $\mu$ )Tsmsteam temperatureTrebreboiler temperatureUoverall heat transfer coefficient $\dot{V}$ solvent volume flow rateufluid velocityWpwidth of each plateWTtotal width of platesGreekcapital cost scaling factor $\Delta$ capital cost scaling factor $\Delta$ Ptotal pressure drop $\Delta$ PLpressure drop per unit length $\Delta$ TLMlog mean temperature difference $\delta$ plate spacing $\eta_p$ pump efficiency  | ṁ                | solvent mass flow rate                |  |
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| ufluid velocity $W_p$ width of each plate $W_T$ total width of plates <b>Greek</b> $\alpha$ capital cost scaling factor $\beta$ capital cost annualizing factor $\Delta P$ total pressure drop $\Delta P/L$ pressure drop per unit length $\Delta T_{LM}$ log mean temperature difference $\delta$ plate spacing $\eta_p$ pump efficiency   |                  | overall heat transfer coefficient     |  |
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| $ \begin{array}{ll} \beta & \mbox{capital cost annualizing factor} \\ \Delta P & \mbox{total pressure drop} \\ \Delta P/L & \mbox{pressure drop per unit length} \\ \Delta T_{LM} & \mbox{log mean temperature difference} \\ \delta & \mbox{plate spacing} \\ \eta_{p} & \mbox{pump efficiency} \end{array} $  | Greek            |                                       |  |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$  |                  |                                       |  |
| $\begin{array}{ll} \Delta P/L & \mbox{pressure drop per unit length} \\ \Delta T_{LM} & \mbox{log mean temperature difference} \\ \delta & \mbox{plate spacing} \\ \eta_p & \mbox{pump efficiency} \end{array}$   |                  |                                       |  |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$  |                  |                                       |  |
| δ plate spacing<br>$η_p$ pump efficiency  |                  |                                       |  |
| $\eta_p$ pump efficiency  |                  |                                       |  |
|   | δ                |                                       |  |
| $\eta_{tb}$ steam turbine efficiency  | $\eta_p$         |                                       |  |
|   | $\eta_{tb}$      | steam turbine efficiency              |  |

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