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IMPACT OF FOULING ON ENERGY MANAGEMENT IN COLUMN HEAT RECOVERY SYSTEM WITH ONCE-THROUGH THERMOSYPHON REBOILER

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ABSTRACT

Stable operation of once-through and thermosiphon reboilers presents a challenge when compared to traditional shell-and-tube heat exchangers due to various factors that can destabilize flow. One such factor, the minimum heat flux, is critical for maintaining a consistent and efficient operation. In the context of a reboiler system, fouling can significantly impact performance by reducing heat transfer efficiency and increasing the pressure drop across the system. This problem was exemplified in a case where a once-through reboiler attached to a distillation column, exhibited a marked decline in performance following maintenance activities of a connected economizer unit. Subsequent analyses and plant tests suggested that operating the reboiler below the required minimum heat flux threshold for stable operation was a potential cause. This insufficient heat flux stemmed from an inadequate cleaning schedule for the heat exchange components, highlighting the importance of regular and appropriate maintenance to prevent fouling. By addressing these issues, insights into the optimal minimum heat flux and the significance of cleaning cycles for maintaining reboiler efficiency were gained. These insights are critical for ensuring the longevity and proper function of reboiler systems in industrial applications, as fouling can lead to a host of operational challenges, including reduced heat transfer, increased energy consumption, and potential shutdowns for unscheduled cleaning and maintenance.

INTRODUCTION

Circulating thermosiphon and once-through reboilers are extensively employed in the process industry due to their advantages such as low operational and investment costs, and space efficiency [1]. These types of reboilers are particularly preferred in chemical and petrochemical plants. However, maintaining stable operation presents a challenge, as the natural circulation is determined by the system pressure drop and the density difference between the two-phase mixture region and the liquid region. This process, which affects the system pressure drop (including the inlet and outlet piping), is crucial for the flow rate and heat transfer, leading to numerous reported operational difficulties [2, 3]. For optimal design and operation, certain criteria or rules of thumb are advised, one of which is operating above the minimum heat flux [4, 5]. A lower heat flux can reduce pumping action and ultimately lead to flow instability. HTRI suggests maintaining a heat flux above 6,000 W/m^2 for efficient operation [1, 5]. HTRI is also conducting research to elucidate the details of operation behavior in the turndown condition.

Distillation is one of the effective methods for the separation process because it has some advantages, such as high-purity products, economies of scale, and simple and well-established technology. However, the distillation tower requires a large amount of energy consumption, approximately 30% of the petrochemical industry, because it involves multiple evaporation and condensation stages [6]. Although several methods allow reducing energy consumption [7], adding intermediate heat exchangers is generally useful.

In the vertical once-through reboiler involved with the extracted distillation tower in ENEOS Kawasaki, as discussed in this paper, an economizer is installed to evaporate liquid from the intermediate stage to make the best use of the enthalpy of the distillation tower bottom (Fig. 1). The feed rate to the distillation tower is controlled by the inlet flow control valve to the distillation tower. The heat input to the distillation tower is controlled by the steam flow rate to keep the temperature at a certain point in the column constant. All liquid is drawn from the intermediate stage and tower bottom feeds to the economizer to maximize the heat recovery. The stream in the distillation tower bottom has a fouling

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tendency, and fouling was also observed in the economizer. Therefore, the operating conditions depend on the degree of fouling and cleaning cycle of the once-through reboiler and the economizer. The economizer was cleaned only in the last turnaround.

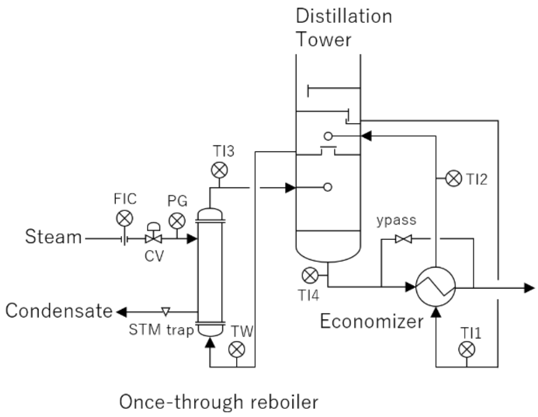

Fig. 1. The configuration of the distillation tower bottom

DISCUSSION

Reboiler Operating Problem

The process involves leading a mixture of C4 and an extraction solvent, which has a wide boiling range, from a chimney tray to the tube side of a once-through reboiler. This mixture is heated by steam, and the resulting two-phase mixture is then returned to the distillation tower. This reboiler has been functioning without issues for 30 years. However, its performance noticeably declined several weeks after the last maintenance turnaround when the fouled economizer was cleaned and the reboiler was not. The steam flow rate dropped suddenly, and consequently, the control valve (CV) opening gradually increased to its full extent over several hours to maintain the same level of heat input. This reduced the feed flow rate, as operating with the CV fully open was challenging. As a result, ENEOS experienced a reduction in production, leading to a significant opportunity loss.

Troubleshooting

The distillation tower model was built using AVEVA PRO/II™ Simulation and the once-through reboiler model including inlet and outlet piping was built using ***Xchanger Suite***® from HTRI to analyze the details of the heat exchanger behavior. These simulation models matched the plant data, and the TW and TI3(or TI4) in Fig. 1 were carefully examined. The tubeside flow rate is constant, unlike in circulating thermosiphon reboilers, but the liquid levels vary to match the pressure drop through the thermosiphon loop, including piping, to the hydrostatic pressure. The hydrostatic pressure affects the subcooled zone length in the vertical once-through reboiler and thermal performance.

Table 1 lists the checks required for stable circulation based on the simulation results. Items 1 through 10 have no discrepancy in comparison with previously published papers and HTRI's rule of thumb. However, regarding item 11, this once-through reboiler operated below the minimum heat flux for stable operation (that is, below 6,000 W/m^2) near the tube outlet. Therefore, we planned to validate our hypothesis in a plant test to increase the heat flux.

Table 1. Once-through reboiler instability checklist

No.	Check items
1	Avoid subcooled instability [8]
2	Avoid drywall boiling
3	Appropriate outlet vapor weight fraction [4]
4	Operating above the onset of nucleate boiling
5	Appropriate pressure balance in the thermosiphon system [4]
6	Appropriate flow regime at the top tube
7	Bouré instability [9]
8	Avoid choke flow
9	Enough ρV^2 at the outlet nozzle and outlet piping [4]
10	Appropriate outlet piping configuration
11	Operating above minimum heat flux for stable operation

The economizer has a bypass line, as shown in Fig. 1. The bypass valve was opened to make the bypass flow approximately half of the total flow rate so that the once-through reboiler inlet temperature decreased and the MTD between the tube side and shell side became larger by reducing the economizer duty (Fig. 2). Consequently, the steam control valve (CV) opening was reduced, leading to an increased steam flow rate.

Interestingly, during this plant test, the result of the CV opening and the steam flow rate decreasing was contrary to the usual pattern observed in this plant. Typically, opening the steam CV would increase the steam flow rate, as was the case during the initial trouble. This CV changes the steam condensing temperature by varying the vapor pressure resulting in controlling the temperature difference between the tube side and the shell side. This suggests that the overall heat transfer coefficient improved and the pressure on the shell side decreased, considering the placement of the steam CV in the inlet line. That is to say, the heat transfer coefficient increased and the required MTD became smaller by increasing the heat flux. Therefore, the pressure on the shell side became lower, and the steam flow rate became higher because there was more room in the CV opening. The film boiling is a possible reason for the lower overall heat transfer coefficient when the CV opening is more open. However, the film boiling is

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not the possible cause since the action to increase the MTD was taken. This possibility was denied by the boiling mechanism analysis in the software as well.

Fig 3 shows the comparison of the local heat flux along the tube before, during, and after the plant test. The heat flux near the tube top was less than 6,000 W/m^2 before and after the plant test but higher during the plant test. We conclude that operating below the minimum heat flux caused an unstable situation and decreased the performance. The result of the plant test was reproducible, and the throughput of the distillation tower could be kept at a normal operation level.

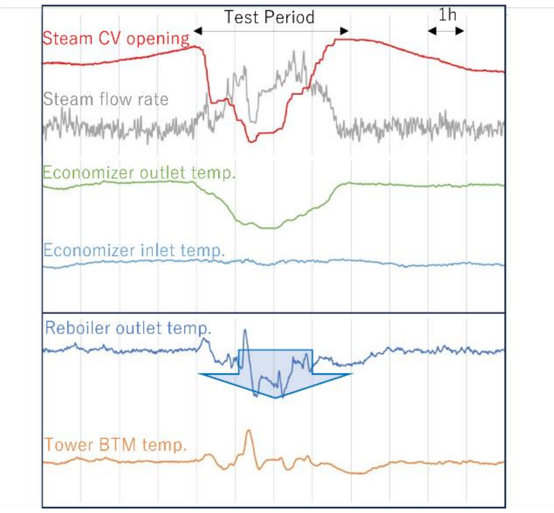

Fig. 2. Trend data of the plant test to increase heat flux(the different y scale was used for the upper 4 trends and the same y scale was used for the lower 2 trends)

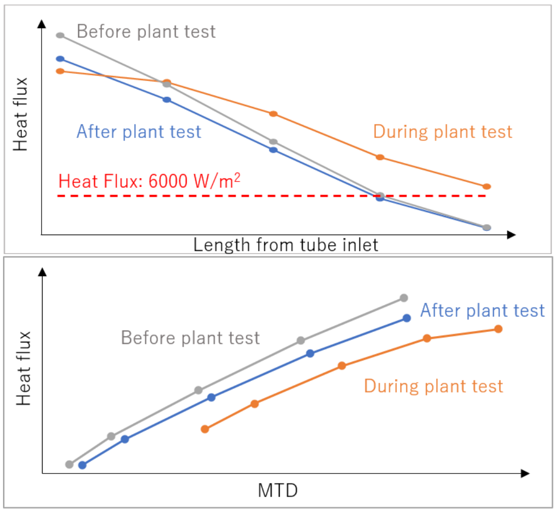

Fig. 3. The comparison of heat flux before, during, and after plant test

Internal Thermosiphoning at Low Heat Flux

The reboiler outlet temperature (TI3 in Fig. 1) and the tower bottom temperature (TI4 in Fig. 1) should be the same because no heat is input between these temperature indicators. However, these temperatures diverged after the last turnaround, as shown in Fig. 4. The possible causes of this phenomenon are 1) the failure of temperature indicators, 2) cold liquid falling from the upper tray due to the tray failure or the overflow by inlet piping blockage or 4) the different composition at the two points.

Regarding the third possible cause, streams at these temperature indicators are in two-phase flow, and the composition should represent the temperature. The internal structure of the distillation tower and the instrumentations were checked in the last turnaround, and no issue was evident. If this temperature discrepancy is related to a mechanical problem, the plant test shown in Fig. 2 should not improve the situation. Temperature discrepancies have been eliminated considerably during the minimum heat flux plant test, and the temperature differences between the reboiler outlet piping and the tower bottom were returned after the plant test again as shown in Fig. 2. These facts indicate that the compositions at these two points should not be consistent. In addition, TI3 was higher than that in typical operation, indicating that the composition near TI3 had heavier components. TI3 is located near the outlet nozzle of the reboiler and it is considered that TI3 is represented by the composition in the reboiler. The higher temperature readings could also imply that operating at a lower heat flux led to diminished pumping action, resulting in an accumulation of heavier components and compositional discrepancies around the reboiler and at the distillation tower bottom, as illustrated in Fig. 5.

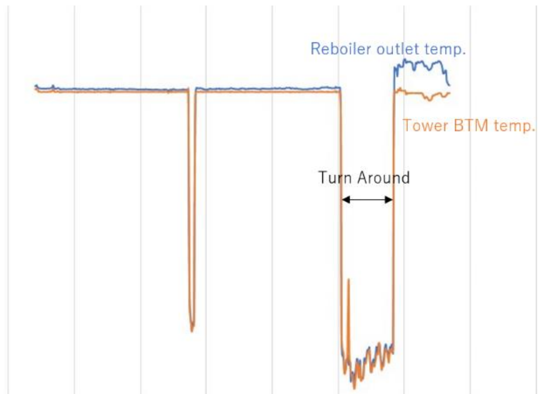

Fig. 4 Trend data of the reboiler outlet and tower bottom temperature

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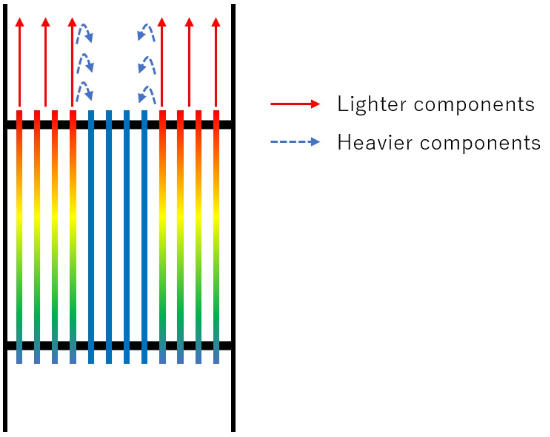

Fig. 5 Proposed internal behavior in the once-through below the minimum heat flux

CONCLUSION

This study underscores the critical interdependence of cleaning cycles in economizer/reboiler systems. Our findings reveal that isolated cleaning of the economizer inadvertently introduced operational instabilities in the reboiler, primarily due to an imbalance in duty cycles. The reboiler then operated below its minimum stable heat flux, resulting in flow instabilities and decreased performance. These observations, derived from analyses conducted using ***X**changer Suite*®, highlight the necessity of a holistic approach to maintenance and cleaning schedules in heat exchanger systems.

Engineers and practitioners in this field are advised to consider the interconnected effects of cleaning individual components on the overall system performance. Such an approach is crucial for ensuring efficient and stable operation of heat exchanger systems.

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