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DETERMINATION OF FEASIBILITY AND
ADVANTAGES OF USING ADDITIONAL
TURBINES TO REDUCE ENERGY
CONSUMPTION AND CO₂ EMISSION OF A
DISTILLATION COLUMN

Article Highlights
• Using additional turbine to produce domestic electricity from process stream in the column
• Reducing the energy consumption from using domestic electricity and reducing CO₂ emission
• The new design is promising with important amount of energy reduction and CO₂ emission
• Equations were derived in detail to prove the process feasibility
• Distillation to feed ratio and reflux ratio were fully investigated as primary variables

Abstract
Distillation is a process that consumes an extensive amount of energy and emits an enormous amount of CO₂. It is attractive to reduce the energy consumption and CO₂ emission for distillation. A new design of distillation is proposed by adding turbines in the vapor process streams before the condenser and after a reboiler to produce domestic electricity. As a result, this new design helps in reducing energy consumption and CO₂ emission. The key variables are the distillate to feed ratio and the reflux ratio because they are the direct factors that control the vapor flow rates supplying the turbines. The distillation of an alkane mixture of C4–C8 commonly found in a petroleum refinery was used as a test model to prove the process feasibility. The energy consumption and CO₂ emission of the new process are reduced to 0.93–0.96 and 0.89–0.90 of the conventional process, respectively. This new design increases process efficiency in terms of second law efficiency by reducing the entropy generation from the conventional distillation at low distillate to feed ratios and reflux ratios. The distillation with additional turbines is promising to reduce energy consumption and CO₂ emission and to increase process efficiency.

Keywords: distillation; turbine; CO₂ emission; energy reduction.

Distillation is widely used for separation, especially in the petroleum and petrochemical industry. A petroleum refinery utilizes distillation techniques heavily to produce petroleum fuels and chemical feedstocks. Therefore, the effort for saving energy of the distillation process is the first priority for the short and long term [1].

Distillation is proven to have low energy efficiency because it is irreversible. A number of research studies have been published about improving the energy efficiency of distillation systems. The total exergy loss in the distillation process consists of 57% from the column, 29% from the condenser, 11% from the reboiler, and 3% from the compressor [2].

According to the largest portion of exergy loss, a number of research publications have targeted the improvement of exergy loss from the column. One of the most attractive methods was the internally heat-
integrated distillation column. The internally heat-integrated distillation column was proposed to increase the energy efficiency of the distillation system. It was first developed targeting binary separation [3, 4]. The idea was to insert the produced heat to the required area within the distillation system. It was not possible to insert the rejected heat from a condenser to the required heat of a reboiler. This violates thermodynamic laws because the heat cannot transfer from a low temperature source (a condenser) to the high temperature sink (a reboiler). The heat from a condenser can be transferred to a reboiler when the vapor from the top of the column is compressed to a high pressure and temperature and released to the reboiler. However, it requires a large amount of energy to compress the vapor to high temperature and pressure and it can be impractical. A tray-by-tray heat integration was then implemented [3-7]. The heat from the rectifying section of the first column was released to the stripping section of the second column. The internally heat-integrated distillation column was also proposed for ternary mixtures [8]. Kim [8] adopted the work from Mascia et al. [9] for separation of \( n \)-pentane, \( n \)-hexane and \( n \)-heptene and from Lee et al. [10] for separation of benzene, toluene, and xylene. There were two heat exchangers between exchanging stages of two columns. Even though Kim [8] showed that the energy savings was over 27% for a condenser and over 30% for a reboiler, the internally heat-integrated distillation seems to be too complicated to install and control if the number of exchanging stages is large.

The other attempt was to improve the efficiency of a reboiler. A gas turbine can be added in the furnace part in a distillation unit. Fuels such as natural gas and light fuel oil can feed the gas turbine to generate domestic power or electricity. This domestic electricity can be reused in the distillation or exported to another unit. The energy consumption and \( \text{CO}_2 \) emission were reduced by 21 and 22% [1]. Additional savings on utility cost can be gained. A gas turbine is used where the furnace is present. The use of a gas turbine also provides heat to the process as well. The process heat duty can be calculated from the model of Smith and Delaby [11] for a stand-alone turbine and the model of Manninen and Zhu [12] for the use of a gas turbine integrated with the process. As shown from Rizk et al. [2], the exergy loss from the reboiler alone was small.

In this paper, the motivation is derived from the exergy loss of both the reboiler and condenser with the total of 40% [2]. The additional gas turbines are added at the vapor stream before the condenser and after the reboiler to generate domestic electricity to reduce the energy consumption and \( \text{CO}_2 \) emission and eventually increase process efficiency. The design is simple to avoid complications in installation and control like an internally-heat integrated distillation but still importantly reduces energy and \( \text{CO}_2 \) emission. This study does not include the effects of a gas turbine at the fuel combustion unit as this has been fully studied [11, 12]. The new design can be added to the internally heat-integrated distillation and the fuel gas turbine to increase the total savings of energy consumption and \( \text{CO}_2 \) emission.

The objective of this paper is to investigate the process feasibility and advantages of the new design of distillation with an additional turbine. The feasibility and advantages were determined by studying the effect of wide ranges of distillate to feed ratio and reflux ratio. These ratios control the vapor flow rates, which affect the capacity of electricity generation of the turbines. As the distillate to feed ratio is one of the variables, the product purity is not considered; otherwise, the study range of distillate to feed ratio will be very narrow. The number of stages and the feed stage are set as general values as they do not affect the main variables. The results of this work can be used as a guide for inserting the turbines to reduce the energy consumption and \( \text{CO}_2 \) emission for existing process with specific distillate to feed ratio and reflux ratio. The distillation of an alkane mixture of C4-C8 was used as a test model.

Figure 1 shows the schematic diagram of the distillation unit with additional turbines. For the top of the column, the vapor stream from the top of the column enters the turbine to generate domestic electricity and then goes to a condenser at lower pressure and temperature. The pressure of liquid leaving the condenser is then increased by a pump to be the same as the vapor leaving the column. For the bottom of the column, the liquid stream enters the pump to increase the liquid pressure in order to produce high pressure vapor in a reboiler to feed the gas turbine. The vapor leaving the gas turbine has equal pressure as the liquid leaving the column. The temperature of the bottom turbine outlet is reduced but still high compared to the bottom tray temperature. Therefore, the exit stream of the turbine with high temperature is used to preheat the inlet stream that enters a reboiler. In this case, the temperature of the exit stream from a turbine can be reduced to the same temperature as the bottom tray in the column and the heat duty at a reboiler can be saved.

From Figure 1, the turbines generate work while the pumps consume work. The condenser rejects
heat while the reboiler requires heat. For additional turbines, the generated work by turbines must exceed the required work by pumps. The rest of the work generated by turbines can be used as external power for refrigeration in a condenser or for steam generation in a reboiler. It is assumed that the power generated by turbines could be recycled to the system without any losses. It is assumed that the condenser duty comes from refrigeration and served by electricity and the reboiler duty is served by direct combustion of fuels for steam generation. Table 1 shows the CO₂ emission factors for the electricity production and the fuel combustion. The CO₂ emission factors already include the efficiency effects on the electricity production and the fuel combustion. According to Table 1, it is wise to insert turbine work to reduce the duty of the condenser not the reboiler because the CO₂ emission for the electricity generation is over two times larger than the fuel combustion.

Turbines and pumps are not present for conventional distillation. It can be expected that the heat duties for a condenser and a reboiler of the new design are different from the conventional design because the temperature and pressure of the streams entering the condenser and the reboiler are different. However, the stream properties of feed, distillate product, and bottom products are equal for both designs. The stream properties include flow rate, composition, temperature, and pressure.

**Theoretical part**

The energy balance is shown in Eq. (1). Equations (2)-(7) are derived from Eq. (1). The heat requirement comes from the change of enthalpy in the flow system and work. In this particular system, a con-

**Table 1. Emission factor of CO₂ (e) for combustion and electricity generation in (kg CO₂ equivalent) per amount of released heat (kW·h) for coals, natural gas, and oils**

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Combustion×10⁻³, kg CO₂ e/kW·h [13]</th>
<th>Electricity×10⁻³, kg CO₂ e/kW·h [14]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Coals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthracite</td>
<td>373</td>
<td>835</td>
</tr>
<tr>
<td>Bituminous</td>
<td>337</td>
<td>830</td>
</tr>
<tr>
<td>Sub-bituminous</td>
<td>350</td>
<td>920</td>
</tr>
<tr>
<td>Coking coal</td>
<td>409</td>
<td>715</td>
</tr>
<tr>
<td>Lignite</td>
<td>347</td>
<td>940</td>
</tr>
<tr>
<td>Average</td>
<td>363</td>
<td>848</td>
</tr>
<tr>
<td>2. Natural gas</td>
<td>Natural gas</td>
<td>191</td>
</tr>
<tr>
<td>3. Oils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy fuel</td>
<td>284</td>
<td>620</td>
</tr>
<tr>
<td>Gas/Diesel</td>
<td>264</td>
<td>65</td>
</tr>
<tr>
<td>Average</td>
<td>274</td>
<td>635</td>
</tr>
<tr>
<td>Total average of 1-3</td>
<td>276</td>
<td>618</td>
</tr>
</tbody>
</table>
denser and a reboiler are the only heat transfer equipment. The heat requirement for equipment is calculated from Eqs. (2)–(5). The work from turbines and pumps is equal to the enthalpy change of the process streams as shown in Eqs. (6) and (7). The net energy requirement for the whole process can be viewed as Eq. (8). The absolute heat duty for the system is the summation of absolute values of heat in the system as shown in Eq. (9). The conventional heat duty is shown in Eq. (10):

\[
\sum_{i} \dot{Q}_i = \Delta [\dot{m}H]_i - \dot{W}_i \quad \text{(1)}
\]

\[
\dot{Q}_\text{Con} = \Delta [\dot{m}H]_\text{Con} \quad \text{(2)}
\]

\[
\dot{Q}_\text{Reb} = \Delta [\dot{m}H]_\text{Reb} \quad \text{(3)}
\]

\[
\dot{Q}_\text{Tur} = \Delta [\dot{m}H]_\text{Tur} - \dot{W}_\text{Tur} = 0 \quad \text{(4)}
\]

\[
\dot{Q}_\text{Pump} = \Delta [\dot{m}H]_\text{Pump} - \dot{W}_\text{Pump} = 0 \quad \text{(5)}
\]

\[
\dot{W}_\text{Tur} = \Delta [\dot{m}H]_\text{Tur} = \dot{m} \left( C_{p,\text{vap}} \Delta T - V_{\text{vap}} \Delta P \right) \quad \text{(6)}
\]

\[
\dot{W}_\text{Pump} = \Delta [\dot{m}H]_\text{Pump} = \dot{m} \left( C_{p,\text{liq}} \Delta T - V_{\text{liq}} \Delta P \right) \quad \text{(7)}
\]

\[
\dot{Q}_\text{Total} = \sum \dot{Q}_i \quad \text{(8)}
\]

\[
\dot{Q}_\text{Total,new} \leq \dot{Q}_\text{Total,conventional} \quad \text{(9)}
\]

\[
\dot{Q}_\text{Total,conventional} = |\dot{Q}_\text{Con}| + |\dot{Q}_\text{Reb}| \quad \text{(10)}
\]

One of the major objectives of this work is to reduce the heat requirement. The output work of turbines generates domestic electricity that can be reused for a pump and the rest is used as external power in a Carnot cycle for refrigeration in a condenser. The absolute heat duty was then derived as Eq. (11) for the new design of distillation with additional turbines. When putting additional turbines in the distillation system, constraints given by Eq. (12)–(14) must be satisfied. The constraints given by Eqs. (13) and (14) are that the work produced by turbines must be larger than the work required by the pump and the remaining work is less than the heat duty of the condenser:

\[
\dot{Q}_\text{Total,conventional} = |\dot{Q}_\text{Con}| + |\dot{Q}_\text{Reb}| \quad \text{(11)}
\]

\[
|\dot{W}_\text{Tur}| \geq |\dot{W}_\text{Pump}| \quad \text{(12)}
\]

\[
|\dot{W}_\text{Tur} + \dot{W}_\text{Pump}| \leq |\dot{Q}_\text{Con}| \quad \text{(13)}
\]

The equivalent CO₂ emission (\(E_{\text{CO}_2}\)) is calculated by Eq. (15), which is the summation of the multiplication of emission factor (\(e\)) and the absolute heat. It is assumed that the heat duty is obtained from the electricity for the condenser and steam production from fuel combustion for the reboiler. The equivalent CO₂ emission is calculated by Eq. (16) for the distillation with additional turbines with the conditions of Eqs. (12)–(14). It is obvious that the emission of CO₂ equivalent for Eq. (16) is less than Eq. (15):

\[
E_{\text{CO}_2,\text{Conventional}} = e_{\text{Elec}} |\dot{Q}_\text{Con}| + e_{\text{Combustion}} |\dot{Q}_\text{Reb}| \quad \text{(15)}
\]

\[
E_{\text{CO}_2,\text{New}} = e_{\text{Elec}} |\dot{Q}_\text{Con}| - (|\dot{W}_\text{Tur}| + |\dot{W}_\text{Pump}|) + e_{\text{Combustion}} |\dot{Q}_\text{Reb}| \quad \text{(16)}
\]

The thermodynamic efficiency of the process can be viewed from the entropy generation. The total generation of entropy, \(S_{\text{G,total}}\), must be greater or equal to zero. A reversible process has the highest efficiency process with zero entropy generation. The goal is to minimize \(S_{\text{G,total}}\) to maximize the efficiency. Entropy balance of the system can be viewed as Eq. (17). In Eq. (17), the entropy generation consists of two parts: the flowing streams and the heat transfer:

\[
S_{\text{G}} = \Delta [\dot{m}S] - \sum \frac{\dot{Q}_i}{T_{\text{Sur},i}} \quad \text{(17)}
\]

The entropy of this system can be calculated by substituting Eqs. (2) and (3) into Eq. (17) to obtain Eq. (18) for a conventional process:

\[
S_{\text{G,conventional}} = \dot{m}_D S_D + \dot{m}_G S_G - \dot{m}_F S_F - 
\frac{\dot{Q}_\text{Con}}{T_{\text{Sur,Con}}} - \frac{\dot{Q}_\text{Reb}}{T_{\text{Sur,Reb}}} \quad \text{(18)}
\]

The surrounding temperature of the condenser is the temperature of the coolant. The coolant temperature must be less than or equal to the minimum temperature of the process stream passing through the condenser. The lowest temperature of the condenser is the temperature where all vapors are completely condensed and that temperature is the bubble point temperature. In the same manner, the surrounding temperature of the reboiler is the temperature of
the heating steam. The heating steam must be more than or equal to the maximum temperature of the process steam passing through a reboiler. The highest temperature of the reboiler is the temperature where all liquids are completely vaporized and that temperature is the dew point temperature. Consider Eq. (18); if the coolant temperature decreases, the entropy generation increases as the condenser heat is negative. In the same manner, if the heating steam temperature increases, the entropy generation increases as the reboiler heat is positive. Therefore, the minimum entropy generation is shown in Eq. (19):

$$S_{\text{min,conventional}} = m_p S_p + m_p S_B - m_p S_F - \frac{Q_{\text{Con}}}{T_{\text{bubble,Con}}} + \frac{Q_{\text{Reb}}}{T_{\text{Dew,Reb}}}$$

(19)

One of the main objectives of this work is to increase process efficiency by reducing entropy generation. If the amount of work of the turbine that is left from using with the pump is recycled to satisfy the heat requirement from the condenser, the minimum entropy generation of Eq. (19) can be rewritten as Eq. (20) with conditions of Eqs. (12)–(14). It was not wise to subtract the turbine work from the reboiler duty as it increases the entropy generation in Eq. (19):

$$S_{\text{min,new}} = m_p S_p + m_p S_B - m_p S_F - \frac{Q_{\text{Con}}}{T_{\text{bubble,Con}}} - \frac{Q_{\text{Reb}}}{T_{\text{Dew,Reb}}} - (W_{\text{Turb}} + W_{\text{Pump}})$$

(20)

An economic analysis of the system is important to evaluate the new design and the conventional distillations in terms of annual costs, capital costs, and payback period. However, the prices of equipment, fuels, and electricity depend enormously on suppliers and regions. As a result, it is very difficult to obtain reliable and consistent prices in order to evaluate the economic feasibility of the new designed distillation. Therefore, the economic analysis of the new designed distillation is not studied here.

**Simulation**

Process simulations were performed to determine the advantages and disadvantages of the conventional distillation and the distillation with additional turbines in terms of heat requirement, CO2 emission, and process efficiency (entropy generation). The test model for the process simulations was the distillation of an equimolar alkane mixture of C4H10, C5H12, C6H14, C7H16 and C8H18 which can be commonly found in petroleum crudes. The mixtures were assumed to be equimolar for studying the process feasibility. The process variables included the distillate to feed ratio and the reflux ratio because they are the main distillation variables that have an effect on the flow rate of vapor passing through turbines, which has significant impact on the amount of work produced by turbines. The purities of distillate and bottom products were not considered. This work is aimed to be an example for the existing process that already has process specifications including product purities, distillate to feed ratio, and reflux ratio, to insert an additional turbine to reduce energy consumption and CO2 emission.

Aspen Plus was used as the process simulator. RADFRAC was the distillation column model. The thermodynamics model was Soave-Redlich-Kwong. The number of stages was twenty and the feed stage was the tenth. The isentropic efficiency of turbine and pump was 0.70.

The distillate and bottom stream pressures were 4 and 6 atm. In Figure 1, on the top part of system, the vapor stream enters the turbine at 4 atm and leaves to the condenser at 1 atm. Then, the liquid from the condenser is pumped to 4 atm to be equal to the pressure at the top of the column. On the bottom part, the liquid stream is pumped from 6 atm to 15 atm to the reboiler. The vapor stream at 15 atm from the reboiler enters the turbine and leaves at 6 atm to be equal to the pressure at the bottom of the column. The pressure drops of 3 and 9 atm are selected for the turbines on the top and at the bottom of the column.

The simulations were run to determine the reduction of heat requirement, CO2 emission, and entropy generation from the conventional distillation with the distillation using additional turbines. The simulations were run in order that the conventional and the new designs had the same stream properties for feed, distillate product, and bottom product. The stream properties include flow rate, composition, temperature, and pressure. The properties of feed, distillate product, and bottom product were fixed in order to have a fair comparison between the conventional and the new designs.

**RESULTS AND DISCUSSION**

Simulations were performed for distillation columns with and without additional turbines. Table 2 summarizes the column operating conditions for the conventional distillation and the new design of distillation with additional turbines at a constant reflux ratio of 1.0. In Table 2, the first column shows the operating conditions and the rest shows the results of four separations. The column of C4H10/C8H16 means that C4H10 is the light key component and C8H16 is the
heavy key component. The distillate to feed ratio is 0.2 because it is an equimolar mixture of five components. The distillate to feed ratio increased by 0.2 for the other systems; for example, the distillate to feed ratios of C₅H₁₂/C₆H₁₄, C₆H₁₄/C₇H₁₆ and C₇H₁₆/C₈H₁₈ are 0.4, 0.6, and 0.8 respectively. The absolute heats for both condenser and reboiler increase with the distillate to feed ratio because a reboiler requires higher heat to vaporize the liquid and the condenser rejects higher heat to condense vapor. The conditions in Table 2 were used to calculate absolute heat duty, CO₂ emission, and entropy of generation. As discussed earlier, the purities of the products were not the focus of this work.

The reduction of absolute heat duty was determined for the conventional distillation and the new design of distillation. According to Table 2, the condenser duty of the new design decrease as a result of the decrease in the condenser temperature. On the other hand, the reboiler duty of the new design is larger than the conventional distillation. According to Table 2, the increase in the reboiler temperature should decrease the reboiler duty. However, the reboiler duty increases because the elevation of bubble point temperature from the increase in the reboiler pressure. The total heat duty in Eq. (11) is reduced from the conventional distillation. Figure 2 shows the plot of the ratio of absolute heat duty of the new design to the conventional distillation against the distillate to feed ratio at various reflux ratios. In Figure 2, the absolute heat duties of the new design of distillation are always lower than the conventional distillation as expected from Eqs. (10) and (11). The reason is that the work produced by turbines is subtracted from the heat duty of the condenser in Eq. (10). The absolute heat ratio decreased with the

![Figure 2. Ratio of absolute heat duty of the new design to the conventional distillation at various distillate to feed ratios and reflux ratios of 1, 2, 5 and 10.](image)
increase of reflux ratio. The increase of reflux ratio increases the flow rate of vapor streams in the system; as a result, a larger amount of work is produced by turbine. However, the heat duties for both condenser and reboiler increase but less than the increase of turbine work. As a result, the increase of reflux ratio has a positive effect on the reduction of absolute heat duty as shown in Figure 2. On the other hand, the distillate to feed ratio has interesting effects on the ratio of absolute heat duty. The increase of distillate to feed ratio increases the flow rates of vapor streams in the system. Again, the increase can be expected for the work produced by turbine and heat duties both condenser and reboiler. In Figure 2, at low reflux ratio, it is useful to increase the distillate to feed ratio, in order to increase the turbine work and subtract the heat duty but not for high reflux ratio. The selection of reflux ratio and distillation to feed ratio came from the specification of the key components including the product yield and purity. It cannot be concluded here how to select the reflux ratio and distillate to feed ratio, but it can be used as a guide from the results shown in Figure 2 from the effects on the reduction of absolute heat duty. The new design of distillation also reduces the utility cost as the heat requirement was reduced.

The reduction of CO₂ emission was determined. Figure 3 shows that a larger CO₂ reduction could be obtained at low reflux ratio, which was the same as the reduction of absolute heat duty. The difference of the reduction of CO₂ emission is larger at low distillate to feed ratios. This comes from the fact that the CO₂ emission factor for electricity is larger than for the combustion.

Figure 4 shows the ratio of entropy generation of the new design to the conventional distillation. In Figure 4, the entropy generation of the new design of distillation is not always lower than the conventional distillation. Considering Eqs. (19) and (20), the entropy generation consists of two parts: flowing streams and heat engines. The flowing stream part is the same for both new design and conventional distillation but not for the heat engines. From Table 2, the pressures of the condenser and the reboiler are different for the new design and the conventional distillation. As a result, differences are expected for the heat duties for the condenser and the reboiler along with the bubble point and dew point temperatures. Figure 5 shows the bubble point and dew point temperatures at pressure according to the condenser and the reboiler versus the distillate to feed ratio. It is logical that the bubble point and the dew point temperatures increase with the pressure and with the distillate to feed ratio. At higher distillate to feed ratio, a larger amount of heavy components flows along with light components to the condenser. As a result, the bubble point temperature at the condenser increased. Also, when the distillate to feed ratio increases, the liquid at the reboiler contains a larger fraction of heavy components. As a result, the dew point temperature at the reboiler increases.

The heat engines were analyzed thoroughly to determine the change of entropy generation. First of all, consider the condenser duty divided by the bubble point temperature in Eq. (19) and (20). The pressures of the condenser were 1 and 4 atm for the new design and the conventional distillation, respectively. The absolute condenser duty was slightly less for the new design of distillation. However, the bubble point temperature of the new design of distillation was much less than the conventional distillation, as shown in Figure 5.
Figure 5. Both an increase of absolute condenser duty and a decrease of bubble point temperature resulted in the increase of entropy generation in Eq. (20). However, the work produced by turbines results in a decrease of entropy generation in Eq. (20). Table 2 shows that the pressures of the reboiler are 15 and 6 atm for the new design and the conventional distillation. The absolute reboiler duty increases while the dew point temperature increases with the pressure; as a result, the entropy generation in Eq. (20) is reduced. As shown in Figure 4, the entropy generation decreases for the new design of distillation at low distillate to feed ratio and reflux ratio or in the region where the flow rates of vapor streams are comparably low.

CONCLUSION

A new design of distillation with additional turbine is proposed to reduce energy consumption, CO$_2$ emission, and entropy generation. The additional turbines generated domestic power for refrigeration in a condenser. Process simulations were performed with various distillate to feed ratios and reflux ratios for both new design of distillation and conventional distillation. The simulation results show that the energy consumption and CO$_2$ emission of the new process are reduced to 0.93-0.96 and 0.89-0.90 of the conventional process, respectively. The entropy generation is reduced 0.81-0.99 of the conventional process at low distillate to feed ratio and reflux ratio. The distillation with additional turbines shows great promise for the reduction of energy consumption, CO$_2$ emission, and entropy generation.

Figure 4. Ratio of entropy generation of the new design to the conventional distillation at various distillate to feed ratios and reflux ratios of 1, 2, 5, and 10.

Figure 5. Bubble point at the condenser and dew point at the reboiler at various distillate to feed ratios and pressures.
Nomenclature

\( C_p \) heat capacity (kJ/kmol.K)

\( ECO_2 \) CO\(_2\) equivalent emission (kgCO\(_2\)e)

\( e \) emission factor (kgCO\(_2\)e/kW.h)

\( H \) enthalpy (kJ/kmol)

\( \dot{m} \) molar flow rate (kmol/h)

\( Q' \) heat flow rate (kJ/h)

\( S \) entropy (kJ/kmol.K)

\( S_{\text{gen}} \) entropy generation (kJ/K.h)

\( W ' \) work (kJ)

Subscript

B bottom stream

bubble bubble point

Con condenser

dew dew point

F feed stream

Pump pump

Reb reboiler

Surr surrounding

Tur turbine

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REFERENCES


ODREĐIVANJE IZVODLJIVOSTI I PREDNOSTI
KORIŠĆENJA DODATNIH TURBINA ZA
SMANJENJE ENERGETSKE POTROŠNJE I
EMISIJE CO₂ KOD DESTILACIONE KOLONE

Destilacija je process koji troši velike količine energije uz enormnu emisiju CO₂. Značajno je smanjiti potrošnju energije i emisiju CO₂ kod destilacije. Predložen je novi dizajn destilacione kolone dodavanjem turbina u parnu fazu ispred kondenzatora i posle isparivača, da bi se proizvela električna energija. Kao rezultat, ovaj novi dizajn pomaže u smanjenju potrošnje energije i emisije CO₂. Ključne promenljive su odnos protoka destilata i napojne smeše i refluxnog odnosa, jer su oni direktni faktori koji kontrološu protok pare koja se dovodi na turbine. Destilacija smeša alke od C₄-C₈, koja se uobičajeno izvodi u rafinerijama nafte, korišćena je kao test model za dokazivanje izvodljivosti procesa. Potrošnja energije i emisija CO₂ novog procesa su smanjene do 0,93-0,96 i 0,89-0,90, redom, u odnosu na konvencionalni proces. Ovaj novi dizajn povećava efikasnost procesa u smislu drugog zakona termodinamike smanjujući entropiju nastalu konvencionalnom destilacijom pri niskim vrednostima odnosa destilat-napojna smeša i refluksnog odnosa. Destilacija sa dodatnim turbinama obećava kao proces za smanjenje potrošnje energije i emisije CO₂, kao za i povećanje efikasnosti procesa.

Ključne reči: destilacija, turbine, emisija CO₂, smanjenje potrošnje energije.