A Review of Strategies for Selecting an Optimal Distillation Column Sequence[1]

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ABSTRACT

This article thoroughly examines the progress in methods for selecting the most suitable sequence of column distillation units to separate multicomponent mixtures. Significant advancements in this field are also discussed. The evaluation includes a variety of methodologies, including sharp and non-sharp separation systems, as well as many complex designs of distillation units. The application of driving force techniques and matrix separation to determine the optimal distillation column sequence is also explored. It is expected that newly developed computational methods will play a main role in accomplishing the appropriate configuration in the systematic design of distillation units in the future. The main focus is on updating the evolutionary techniques of computing by which we can deduce the optimal distillation column sequence.

Keywords: *Sequences; Energy-Integration; Design; Distillation; Optimization*

INTRODUCTION

The foundation of chemical engineering lies in process design, which facilitates the efficient and effective separation and production of pure products according to specific requirements [29, 52]. The significance of process design and its economic advantages have been recognized as the production of chemicals has scaled up, in conjunction with escalating environmental concerns [39, 87]. Initially, process design relied on knowledge of existing comparable processes, which were then enhanced through the use of case-based reasoning to create innovative designs [73, 86]. Even large-scale facilities were designed based on scaled-up laboratory processes. The introduction of computers enabled process modeling, which leads to increased knowledge of chemical processes during the design process. These advancements in simulation gave rise to process systems engineering, which optimizes the design and further enhances chemical processes [7, 84]. Over time, these tools became more widely available, and intricate mathematical models emerged as the latest strategy for enhancing process modeling accuracy, granting designers increased flexibility to explore more options and transform ideas into reality. Proper process design holds substantial value as it leads to significant cost reductions and energy conservation [87].

In the US, there are estimated to be over 40,000 operational distillation columns, consuming energy equivalent to 1.2 million barrels of oil per day [36]. To minimize overall energy consumption and adhere to cost constraints, it is crucial to optimize the efficiency of these processes at the given scale of operation. Distillation, for achieving separation, relies on exploiting the different boiling temperatures of the constituent parts of a mixture [42]. Energy is required for heating the reboiler, functioning as a high-temperature heat sink, while the condenser serves as a lower-temperature heat source that requires cooling. External utilities are typically necessary for these processes. As a result, efforts have been made to apply energy- and cost-saving measures through the integration of external heat sources and distillation columns [76].

Liquid phase separation plays a pivotal role in the chemical industry, with distillation being the most widely used method [11]. Approximately 95% of the processes resulting from distillation are mainly focused on the separation of the liquid phase. Moreover, these processes consume between 40 and 60 percent of the energy used in the chemical and refining industries, accounting for nearly 3 percent of world energy consumption [31, 37, 74]. This highlights the importance of effective thermal integration to reduce energy consumption, as the cooling and heating facilities play a

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significant role in overall energy usage. Distillation, being the most prevalent separation system, is also the most energy-intensive [72]. Many researchers have concentrated on multicomponent distillation sequencing [40]. Designing the best separation order for various procedures poses a challenging combinatorial problem [2, 12, 49]. As the number of components in the feed stream increases, the number of potential solutions for the problem also increases [2, 5, 29]. There are various approaches to separate multicomponent mixtures and producing the same products. However, even among alternative distillation sequences that produce the same products, fixed and operating costs, as well as energy needs, might vary significantly [14, 20, 26].

With a focus on simplicity and energy integration, this research explores key ideas related to sequencing distillation columns. It examines various methods for choosing the best arrangement of columns while considering both sharp and non-sharp separation schemes. The paper also discusses several sophisticated distillation column designs.

HEURISTIC GUIDELINES AND HEURISTIC-BASED EVOLUTIONARY TECHNIQUES

The importance of Heuristics guidelines in determining the sequence of distillation columns

In distillation columns, heuristics are crucial for choosing the best order and lowering the amount of energy used [41]. Early on, selecting methods mainly relied on the designer's expertise and intuition [32, 90]. These heuristics are useful for decreasing the number of sequences that need to be carefully evaluated, especially when dealing with a large number of components to be separated, notwithstanding their contradictory nature [29, 82]. As a result of the increase in the paths of the distillation process and its many complications, a method was used to select candidates from the sequence by heuristics [32, 35]. They have proven to be crucial tools in the synthesis phase of design [36, 49]. Heuristics, such as favoring the separation of the lightest component or the component with the highest molar fraction at the initial stage, have historically had a significant impact on the choice of the best separation sequences [85]. In circumstances requiring multicomponent feedstocks, heuristics have frequently been used to select the best arrangement of distillation columns [54, 57, 92].

Selection of the optimal sequence for non-integrated distillation columns

To assist in selecting the appropriate sequences, heuristics methodologies were proposed, all of this is for non-thermally integrated and direct distillation columns. These heuristics were developed in order to generalize observations made in various problems. While several heuristics have been suggested, they can be summarized as follows:

a. When the relative volatility of key components is close to unity and there are no non-key components, separation should be carried out.

b. Preferably, the sequences in the column overheads eliminate components one at a time.

c. Favor sequences that cause the feed to be distributed between the distillate and bottom products more evenly.

d. Save the last sequence in the series for sequences with exceptionally high specific recoveries.

It is important to note that these heuristics are applicable only to simple columns and assume no heat integration, meaning that all the reboilers and condensers are supplied by utilities. Difficulties may arise when the heuristics are conflicting with each other [21, 25, 27, 42, 54].

Table 1: An overview of the most important heuristic rules' development and progression through time.

Author	**Year**	**Heuristic rule**
Harbert	1957	First, carry out the simplest separation
Heaven King	1969 1971	Carry out the equimolar divides (50/50)

Rudd Hiraizumi and Nishimura King	1971 1971 1971	Take out the component that is most abundant initially
Harbert Rudd	1957 1973	First, the cheapest split
King	1971	Make a direct sequence
Rudd	1973	The biggest split last
King Gomez and Seader	1971 1976	Execute a sequence without any non-essential elements
Nath	1981	Use the smallest separation difficulty factor for the used separation
Lien	1983	Separate using the energy index with the lowest value
Nadgir and Liu	1983	Use the highest separation difficulty factor for the used separation

Innovative techniques and evolutionary strategies for choosing the best distillation sequence

Freshwater & Henry (1974) and Heaven (1969) conducted studies to select the best distillation column sequence, focusing on design as well as energy consumption and the resulting financial losses. In their studies, they used shortcut procedures based on recognized methodologies such as the Erbar-Maddox correlation and Underwood's method. These studies showed agreement in their findings [17–19, 27]. Both straightforward serial distillation arrangements and more intricate systems with side streams and various feeds were evaluated by Tedder and Rudd in 1978. They sought to reduce venture expenses, which were based on annual operating costs and total capital expenditures [81–83].

Finding the best column configuration in terms of cost and usability is the major objective of a distillation-based synthesis challenge. However, Hendry and Hughes (1972) and Rodrigo and Seader (1975) found that the work of synthesizing the ideal distillation column becomes difficult due to the enormous number of alternative arrangements when the feed consists of more than three components. This complexity has necessitated the reliance on heuristics and evolutionary methods to tackle the combinatorial issues involved [28, 67, 72].

Henry (1976) conducted a study to assess the effectiveness of several heuristics and found that significant energy savings could be achieved. However, a significant obstacle arose in the inability to determine the process conditions under which each heuristic would yield the optimal configuration. Different heuristics could propose varying configurations even under the same process conditions. Mathematical modeling was investigated to deal with this problem. However, Henry (1976) came to the conclusion that this strategy was insufficient. Consequently, the study delved into the concept of pseudo-components, which enabled a better understanding of the interaction between heuristics [30].

Nishimura et al. (1979) and Rod and Marek (1959) introduced mathematical models as instruments for figuring out the best sequences. Due to these experiments, a new heuristic was created that encouraged the early elimination of superfluous components from the feed. In 1973, Rudd, Powers, and Siirola suggested a number of heuristics, including King's heuristics, for sequencing separation processes [56, 66, 69]. Ichikawa and Fan (1973) proposed an analytical tool called Evolutionary Search for Optimal Structure (ESOS) for determining the optimal process route. The most efficient structure was chosen using the continuous function used by ESOS to characterize the system [38]. For column sequencing, a Thermodynamic Optimality index-based optimality criterion was suggested [47, 59, 60]. This criterion is related to the network consumption involved in liquid mixture separation and aligns with the principles laid out in King's work (1971).

Table 2: A concise list of the primary uses for evolutionary tactics and heuristic rules

These are novel studies of different arrangements based on the cost and design of the distillation units. Lockhart came to the conclusion that the optimal design is one in which the components are removed in decreasing order of volatility.	Lockhart (1947)

proposed mathematical models that use the total vapor flow rate as the primary economic parameter to synthesize the separation sequence.	Nishimura et al. (1971), as well as Rod and Marek (1959),
The thermodynamic optimality index was proposed.	Maikov et al. (1972) and Petlyuk et al. (1965)
Revealing the relationship by which the number of formations of a separation process can be calculated depending on the components present in the process based on the distillation of multicomponent feedstock.	Heaven (1969)
For the purpose of separating liquid mixtures, heuristics serve as guides.	Heaven (1969) and King (1971)
Used shortcut techniques to select the best possible sequence.	Freshwater and Henry (1974, 1975) and Heaven (1969)
Expressed the opinion that when the feed contains more than three components, synthesis of the ideal distillation column turns into a difficult combinatorial challenge.	Rodrigo and Seader (1975) and Hendry and Hughes (1972)
focuses on the necessity of using heuristics and evolutionary techniques.	Seader and Westerberg, (1977)
The proposed concept of pseudo components.	Henry (1977)
evaluated both an extra complicated system with many feeds and side streams and simple serial distillation configurations using heuristic optimization.	Tedder and Rudd (1978b)
Techniques for the systematic synthesis of beginning sequences for non-sharp multicomponent separation have been proposed, and they have been based on heuristics.	Cheng and Liu (1988), Nath et al. (1988), and Nath (1977)
An approach called marginal vapor flow (MVF) has been proposed and using this approach leads to satisfactory results without the need for a complete distillation column design and financial cost estimates.	Modi and Westerberg (1992)

COMPUTATIONAL AND KNOWLEDGE-BASED APPROACHES: ALGORITHM-BASED METHODS

Knowledge-based Methods (Genetic Algorithm, Artificial Neural Networks, and Fuzzy Logic)

Due to factors like product quality, international market competition, environmental concerns regarding hazardous waste, and the uncertainty surrounding energy availability and costs, it is now very necessary to improve the equipment needed for the process as well as the technical management and the methods used for improvement. This requires the incorporation of previously overlooked factors into the design of manufacturing processes [80]. Fuzzy logic and artificial intelligence have made advanced tools for synthesis design available [16, 57]. These technologies enable more precise and faster solutions compared to traditional methods. Artificial intelligence speeds up exploration efforts by generating effective search techniques [88].

With the increasing demand for quality products within strict time constraints, the industry faces challenges in meeting them while prioritizing energy conservation and environmental concerns. The industry is using automatic control approaches, which are more effective at satisfying these needs, to address these issues.

Piumsomboon and Thitiprayoonwongse (2001) devised a "new" approach to deal with the distillation sequence because it is considered a combinatorial problem in itself, and they also described the method of dealing with the genetic algorithm in a simple way to solve such a problem. A genetic algorithm is an optimization method that draws inspiration from genetics and natural selection, in which only the most effective adaptations survive. In their method, an initial set of chromosomes was created by encoding the distillation sequences into chromosomal structures. Fitness values were calculated, considering all boundary conditions, and those with the highest scores had the highest probability of being selected for the next generation. Reproductive processes, including duplication, crossover, and mutation, were used to create the new population. The study investigated the effects of genetic algorithm factors on the convergence rate, including population size, reproduction, crossover, and mutation probabilities [62]. Table 3 gives a quick overview of the uses of algorithm-based approaches.

Computation Methods Using Dynamic Programming and Heuristics

Since the 1960s, there has been a growing focus on optimizing the sequencing of multicomponent distillation trains in the field of process synthesis. Several studies have addressed this topic, including the works of Hendry, Rudd, and Seader (1973), Thompson and King (1972), Rathore, Wormer, and Powers (1974), Hendry and Hughes (1972), Powers (1972), and Freshwater and Zigou (1976). These studies have incorporated heuristics and dynamic programming techniques, often implemented in computer programs, to establish the best sequence for all separation procedures, not just distillation. Advanced programs were constructed employing various algorithms and heuristics suggested by the respective researchers, as detailed by Powers (1972) and Thompson and King (1972). Building on Heaven's (1969) five-component feedstock approach, both researchers, Rathore, Wormer, and Powers (1974) focused mainly on the best-in-class energy-efficient design of multi-component trains using conventional distillation columns [27, 63, 64, 84, 93].

Multi-component mixtures containing predominantly zeotropic components for which optimized distillation flow sheets have been carefully constructed using a dynamic programming approach, which is based on the Bellman method. In this approach, flowsheets are created step-by-step, from the last to the first feasible variant, at each step, the minimum amount of expended energy must be taken into account, as well as the optimal variable must be determined. For azeotropic mixtures, the number of flowsheets generated is entirely based on the number of components that must be separated [6, 90, 91].

Table 2 A brief list of algorithms-based techniques' uses (both computational and knowledge-based approaches)

Investigated the synthesis approaches of programming and heuristics using unique computer methodologies.	Hendry and Hughes (1972), Powers (1972), Rathore, Wormer, and Powers (1974), Hendry, Rudd, and Seader (1973), Thompson and King (1972), Powers (1972), and Freshwater and Zigou (1975).
This person using dynamic programming has experimented with the problem that generates energy-integrated distillation trains.	Rathore et al. (1974)
The most prevalent problem in the realm of process synthesis is reportedly the synthesis of heat exchanger networks. Following that, the synthesis of the chemical pathways, separation systems, control systems, and overall flow schemes is displayed.	Nishida et al. (1981)
artificial intelligence was used in the search, and it was discovered that by producing effective search methods, it reduced the amount of time needed for the search.	Wahyu (1990)

To determine the best possible sequence, the Genetic Algorithm (GA) was used as an optimization approach.	Piumsomboon (2001)
outlines a novel method for choosing specific separations and synthesizing separation procedures. The approach is based on Case-Based Reasoning (CBR), which repurposes previously used design instances. Before conducting any deep simulation analysis, all possible alternatives to the process must be evaluated in the initial process design, and this is the main goal of the method.	Seuranen et al. (2005)
The procedure is detailed in detail. The results showed that the energy consumption in the multicomponent distillation (per mole of the mixture) depends mainly on the efficiency when the capacity is constant and the reversible separation process. The ideal order is advised to be the appropriate order. Thermal coefficient values are used to calculate this, and the necessary algorithms are presented.	Tsirlin et al. (2019)

SHARP AND NON-SHARP SEPARATION USING SEQUENTIAL APPROACHES FOR DUAL AND INTEGRATED ENERGY DISTILLATION COLUMNS

On the basis of energy integration and heat stream matching, sequences were chosen.

Two guidelines for limiting the use of heat in the configuration of separation processes with distillation trains were first presented by Harbert (1975). The first principle involved considering minimum quantities for difficult separations as an advantage, similar to King's heuristic. King's heuristics are also reflected in the second principle, which deals with the benefits of establishing a 50/50 split.

To merge these principles and address any potential issues, Harbert proposed an equation as the criterion for column sequencing.

$$\sum MHF = \frac{T_2}{T_2 - T_1} \qquad (1)$$

This equation incorporated various factors, such as the mole overhead product multiplied by the latent heat of vaporization (MH), a correction factor (F) for non-key components, and the boiling points of the heavy (T_2) and light (T_1) keys. Harbert emphasized that the cost of providing heat was the most crucial factor in selecting the optimal sequence [25].

The first to use the investigation the issue of constructing integrated distillation trains using the dynamic programming method was Rathore et al. (1974). They used semi-heuristics, initially optimizing column pressure as a fixed parameter before switching to fixed column pressure [64]. A branch and bound algorithm was created using the Lagrangian method [49, 78]. When creating heat-integrated distillation sequences, the objective function of Naka et al.'s (1982) research was to minimize the loss of available energy. The concept of the pinch point, which includes the heat integration of distillation columns within the overall process, was developed by Linnhoff et al. (1983), garnering much acclaim. When using thermodynamic objective functions to address the synthesis issue, Gomez and Seader (1985) based their findings on the ideas of irreversible second law analysis and the least reversible work of separation [21, 45, 53].

Despite numerous studies on multicomponent distillation, an important unresolved problem pertains to the determination of the appropriate separation sequence and the minimal energy requirement for the process [24, 35, 42, 61]. The choice of separation sequence has a significant impact on energy consumption, particularly heat energy, as it affects the temperatures of the streams involved [65].

Thermally connected distillation column topologies were studied by Aggarwal (1996) for the separation of near-ideal multicomponent mixtures having four or more components. Their study utilized a comprehensive superstructure that encompassed all known configurations and introduced substructures with new configurations for mixtures containing four or more components. Only a reboiler and a single condenser were used in these instances. According to the study, under these circumstances, 4n - 6 provides the least number of necessary correcting and stripping sections [2].

$$S_n = \sum_{j=2}^{n-1} \sum_{m=1}^{j-1} S_{j-(m-1)} \, S_{n+1-j} \qquad (2)$$

Aggarwal (1996) proposed the above equation, which should only be used when $S_2 = 1$, and it is true for $n \geq 3$. The Petlyuk configuration for n = 3 is given by $S_3 = 1$, where n is the number of components and S_n is the total number of potential configurations. The article goes on to say that it might be able to create a recursive formula for the total number of S_n potential configurations for an n-component combination [2].

Selecting the separation sequence and figuring out the best heat exchanger network are the two key problems with heat integration of distillation processes. Westerberg et al. (1981), Westerberg (1985), Liu and Cheng (1988), and Aly (1997) all put forth different strategies. [3, 13, 57, 94]. Cheng and Liu (1988), Bamopoulos et al. (1988), and Nath (1977) all used heuristic methods to synthesize starting sequences for non-sharp multicomponent separation [13, 54, 55]. By applying a bounding technique to determine the minimum number of columns required to separate a single multi-component input into several products, Wehe and Westerberg (1990) were able to accomplish non-sharp separation [89].

Thermal coupling ideas come from the works of Petlyuk and Platonov et al. (1965, 1966) and Lockhart and Stupin (1972) and, whilst energy integration ideas such as heat stream matching were introduced in research by Van Wormer et al. (1974) and Zigou and Freshwater (1976) [19, 59, 60, 64, 79]. These concepts showed the potential for achieving greater energy conservation compared to conventional columns. In order to find streams that might be used for energy integration, Rathore et al. established a feasibility matrix and set of rules by applying energy integration to a five-component feedstock defined by Heaven (1969) [27]. For four and five-component feedstocks, Freshwater and Zigou (1976) investigated the impacts of several process variables on energy integration, highlighting the advantages of energy savings and the consequences of factor perturbations [19].

The concept of "Pinch Technology" was developed as a result of the work by Linnhoff (1979) and Hohmann (1971). By identifying the pinch point, which is represented by the temperature limit, this idea focuses on determining the lowest utility requirements within heat exchanger networks and overall process design. Distillation separation procedures were revolutionized by matching hot and cold streams with a predetermined minimum temperature difference at the pinch point. This allowed for the development and derivation of heuristics for choosing the best order of separations [33, 44, 29, 43, 48, 68].

Selection of Sequences Using Thermally Coupled Distillation Columns and Petlyuk Columns

Thermal coupling is an energy-saving concept in multicomponent distillation that reduces the number of required heat exchangers. Petlyuk first proposed this idea in 1965, and Stupin and Lockhart (1972) expanded on it [23]. No matter how many components are being separated, the Petlyuk column configuration is unique in that it only requires one reboiler and one condenser for the entire distillation process [59, 79]. While there have been several investigations on the Petlyuk column arrangement for three-component mixtures, there is a lack of information for mixtures with more than three components [10]. The Petlyuk column arrangement requires n (n-1) sections for separation for $n \geq 4$ components, which is a significant increase from the 2(n-1) sections in traditional designs with numerous reboilers and condensers [59, 70].

Tsirlin et al. (2019) proposed a rigorous method that recommends the optimal separation sequence based on the monotonous dependence of energy consumption on efficiency in multicomponent distillation when capacity is constant and separation is reversible. The method involves calculating thermal coefficients using suggested algorithms [85]. Caballero and Grossmann (2004, 2014) describe a novel superstructure optimization and mixed integer nonlinear program (MINLP) method to create zeotropic mixture distillation sequences. Their method considers various configurations, including traditional distillation sequences, totally thermally coupled series, and divided wall columns. It employs a two-step process where the best configuration is selected from among thermodynamically equivalent options in the first stage and a task sequence is selected in the second. The model is formulated as a generalized disjunctive programming problem using the Underwood-Fenske-Gilliland approximation [8, 9].

As there are more components in the mixture to separate, there are more design options for distillation. For instance, there might be more than 500,000 possible combinations for a six-component mixture [71]. To identify distillation configurations, Gooty et al. developed a mixed integer nonlinear programming tool (MINLP) based on total vapor duty as a proxy for energy usage. Using an in-house visualization software program, they narrowed the search area to a few combinations and put these configurations through rigorous simulations to find the best option for a particular application [22]. Table 4 lists distillation column sequencing methods that are heat-integrated and thermally linked.

Table 4: a succinct review of the ways that heat-integrated and thermally connected distillation columns have been used

No matter how many components are being separated, the Petlyuk column configuration is unique in that it only requires one reboiler and one condenser for the entire distillation process.	Petlyuk et al. (1965)
Research has been conducted on distillation columns that are thermally coupled.	Lockhart and Stupin (1972) and Petyluk et al. (1965, 1966)
A problem-solving approach was created based on the principles of pinch technology.	Hohmann (1971) and Linnhoff (1979)
Begin the efforts towards developing energy-integrated distillation trains.	Rathore et al. (1974)
The idea of energy integration by matching heat streams.	Freshwater and Zigou (1976) and Van Wormer et al. (1974)
The propagation of two principles that aim to reduce heat usage in the configuration of distillation column trains for separation processes.	Harbert (1975)
participated in the development of heat-integrated distillation sequences with a target function of reducing the loss of available energy.	Naka et al (1982)
Thermally connected distillation column designs were used to study the separation of nearly ideal multicomponent mixtures having four or more components. According to the analysis, 4n–6 rectifying and driving sections are the absolute least number needed under these circumstances.	Agrawal (1996)
This study demonstrated a novel method for zeotropic mixture distillation sequence optimization using mixed integer nonlinear programming (MINLP) and superstructure optimization. These techniques account for divided wall columns and completely thermally connected distillation sequences. The selection of a task sequence in the first stage of a two-stage method, followed by the determination of the best possible arrangement of the actual columns from all potential arrangements, has been suggested.	Grossmann, I. E., and Caballero, J. A. (2004, 2014)
This paper explains a simplified superstructure that employs a discrete grid to compute temperatures, resulting in a reduced number of configurations. When side streams are not included, according to the model, expenses can be decreased by 30% in comparison to a simple heuristic method. Furthermore, the cost reduction could increase to 50% if just a few extra process streams are taken into account.	Leeson (2018)
The article proposes a formal approach to show how the efficiency influences the energy needed per mole of the mixture to be separated in multicomponent distillation in a monotonically increasing manner if the capacity is constant and the separation is reversible. The suggested order for such dependency is referred to as the "related order". The necessary procedures and calculations for determining this order are provided, including the computation of thermal coefficient values.	Tsirlin et al. (2019)

THE DRIVING FORCE METHOD AND THE SEPARATION MATRIX BY CHOOSING THE OPTIMAL SEQUENCE OF THE DISTILLATION COLUMN

"The design and optimization of distillation columns are of utmost importance in various industrial processes. A significant challenge in this design lies in determining the most efficient sequence of column sections to achieve the desired separation results. Two commonly used methods to address this challenge are the Driving Force Method and the Separation Matrix. In this review, we will thoroughly explore these methodologies, their benefits, and their applications, providing a comprehensive analysis of how to establish the optimal sequence in distillation columns.

The Driving Force Method is a widely employed technique for determining the optimal sequence of distillation column sections. This method involves calculating the driving forces for each component in the feed mixture at each stage of the column. These driving forces signify the difference between the actual composition and the desired composition of the components at a given stage. By considering these driving forces, engineers can identify the most appropriate arrangement of column sections to maximize separation efficiency. Several studies by Ahmed et al. (2015), Mustafa et al. (2015), and Zaine et al. (2015) demonstrated that the sequence recommended by the driving force method can significantly reduce energy consumption and lead to potential energy savings of up to 7% to 34.84% [1, 51 and 95].

Another effective approach for determining the optimal sequence in distillation columns is the Separation Matrix method. This technique involves constructing a matrix that quantifies the separation efficiency between various components in the feed mixture at different stages of the column. By analyzing this matrix, engineers can pinpoint the optimal arrangement of sections that yields the highest separation efficiency. Studies by Amin et al. (2020) and Elham et al. (2021) showcased the advantages of the separation matrix approach in achieving optimized separation efficiency and improving energy efficiency in various complex configurations [4,15].

Both the Driving Force Method and the Separation Matrix offer their own advantages and unique features. The Driving Force Method provides a straightforward and intuitive approach to determining the optimal sequence of sections based on component driving forces. It allows for a clear understanding of the driving forces behind the separation process and enables easy adjustment of operating conditions to achieve the desired separation. On the other hand, the Separation Matrix approach allows for a comprehensive analysis of separation efficiency between components, leading to refined designs and improved energy efficiency.

A combination of these two methodologies can yield even better results, as they complement each other's strengths. By utilizing the Driving Force Method to identify potential optimal sequences and then employing the Separation Matrix to further refine the design, engineers can achieve enhanced separation efficiency and reduce energy consumption in distillation columns [34,46,58,75,77].

CONCLUSIONS

Chemical processes commonly utilize a series of separators to extract multiple products from complex mixtures. The process of designing and optimizing these distillation sequences holds great importance in process systems engineering, as it can constitute a substantial portion of the capital investment in a chemical plant. Energy optimization is a key focus in the industry, as a significant portion of operating costs is attributed to utility consumption in distillation sequences. However, existing optimization techniques have faced criticism for their inefficiency in synthesis problems and the lack of clarity in their physical functioning. While heuristics and thermodynamic targets have been useful in heat recovery, they have not met the diverse demands in synthesis, and further optimization is not guaranteed. An important outstanding challenge in multicomponent distillation is the finding of an energy-efficient separation procedure. Most studies have focused on lowering the energy requirements for sharp separators, but more research is needed on heat integration for sequences that allow component distribution across top and bottom products as well as for sloppy separations. The current methods are unable to accurately describe all physical phenomena and technical techniques. Engineers use heuristics and experience to speed up the design process in the beginning before moving on to more complex methods. With more components in the mixture, there are more configuration options for distillations, and each configuration has a different energy consumption profile under various situations. With the advent of advanced tools, various methodologies such as Artificial Neural Networks, Genetic Algorithms, Case-Based Reasoning, Driving Force, Separation Matrix, and Fuzzy Logic techniques are now commonly used. However, there is a pressing need for comprehensive and systematic investigations into these methodologies. Optimizing distillation sequences to conserve energy still presents a complex challenge. Further research is essential to develop systematic approaches that take into account a broad spectrum of physical phenomena while integrating newer optimization techniques to enhance the effectiveness and efficiency of the design process.

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