Desalination and Water Treatment
www.deswater.com

31 (2011) 305–310
July

doi: 10.5004/dwt.2011.2355

The use of computer aided techniques for revere osmosis desalination layout design

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Received 13 October 2010; Accepted 29 April 2011

ABSTRACT

This paper presents an efficient solution approach for large-scale, desalination process plant layout problems based on revese osmosis (RO) technology. The final plant layouts (i.e. coordinates and dimensions for each equipment item) are determined from an initial feasible solution followed by an iterative improvement procedure based on computer aided algorithms. The applicability of the solution algorithm is demonstrated through an illustrative example (125,000 m^3/d). The computational results indicate that the proposed approach successfully achieves good quality solutions based on the objective function (short response time, and flexibility) for seawater desalination plants with modest computational requirements.

Keywords: Computer aided techniques; Desalination plant design; Plant layout

1. Introduction

Facilitiy layout is one of the key areas, which have a significant contribution towards manufacturing productivity in terms of cost and time, and a layout has a direct impact on the operational performance, as measured by manufacturing lead time, through put rate and work-in-process [1]. Nowdays, plant layout has been considered as one of the most important issues in the design stage of process plants due to the increasing competition in process industries, restrict environment regulations and product specifications [2]. Moreover, a reasonable plant layout is also linked to crucial safety, engineering, economic and management considerations [3]. Thus it is evident that having an effective layout is critical for productivity improvement in an enterprise.

To support the above decision making process suitable measurement models are required as a pre-requisite, since the performance measurement provides inputs to an optimisation problem, i.e. decision making problem. Numerous researchers have developed different models for facility layout problem since 1960s. The review of such models is available in several sources [4–7].

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Presented at EuroMed 2010 — Desalination for Clean Water and Energy: Cooperation among Mediterranean Countries of Europe and MENA Region, 3–7 October 2010, David Intercontinental Hotel, Tel Aviv, Israel. Organized by the European Desalination Society.

Initially, facility layout was formulated as quadratic assignment problems (QAP), which consider equal-sized units only- such problems were solved using heuristics, branch-and-bound algorithms, fuzzy logic, stochastic optimization and dynamic approaches [8–11]. In addition, facility layout can be tackled by graph theory approaches considering units and connections as nodes and arcs and maximising the adjacencies among nodes [12].

Finally, mathematical programming has been applied to develop various facility layout models including a mixed integer programming (MIP) model where a distance-based objective function, mixed integer linear programming (MILP) and mixed integer nonlinear programming (MINLP) [13]. Recently, facility layout was reformulated as the sequence-pair representation and MIP-based approaches were developed to find the optimal solutions efficiently [14,15].

In this work, the main focus is on heuristics and the process plant layout problems (seawater desalination) which help process engineers build chemical process plants reasonably and economically in the design stage of a new plant or during the improvement phase of current flowsheets. Process plant layout has attracted attention within the research community since it considers various production, environmental and safety issues in process industries. Initially, a number of heuristics were proposed to tackle various process plant layout problems [16]. The Section 2 of the paper presents CORELAP and ALDEP algorithms and Section 3 presents the objective function. The Section 4 briefs the reader on the test case (the implementing seawater desalination plant design), and its results. A discussion of the findings follows.

2. Computer aided plant layout packages: CORELAP (COmputerized RElationship LAyout Planning) and ALDEP (Automated Layout DEsign program) algorithms

Two major obstacles exist to finding efficient layouts: (1) few layout problems result in standardized solutions, and (2) the large number of assignments that are possible (Fig. 1) [17]. Generally there are two types of algorithms: construction and improvement.

Construction algorithms, as the name implies, generate a facility layout from scratch. This type of algorithm starts with an empty layout and adds one facility (or a set of facilities) after another until all the facilities are included in the layout. The differences among various construction algorithms have something to do with the criteria used to decide: (i) The first facility to enter the layout, (ii) Subsequent facility or facilities added to the layout, and; (iii) Location of the first (and subsequent) facilities in the layout.

Improvement algorithms are based on the notion that better layout alternatives can be found through subsequent improvements to the existing layout. The algorithms take the initial layout from the users, modify the layout and evaluate the resulting modified solution. If the result satisfies the desired criteria, better objective function value (OFV), for example, the modification is made; otherwise, the modification is rejected. The improvement is continued until there is no better layout or some exiting criteria are reached. The pair-wise exchange algorithm is a well-known improvement algorithm. Also, known as 2-opt algorithm, the pair-wise exchange algorithm modify the existing layout by systematically exchanging two departments, evaluating the OFV, and deciding whether to accept or reject the modified layout. The procedure is carried out until all possible pair-wise exchanges are considered [7].

The size and complexity of layout problems result in planners relying upon heuristic rules to guide trial-and-error efforts to obtain a "good" solution to each unique problem. In order to sove this difficulty ALDEP and CORELAP (that are construction algorithms) both use preference ratings (a measure of the relative importance for items to be paired or located in close proximity) which reflects subjective input from analysts or manag-

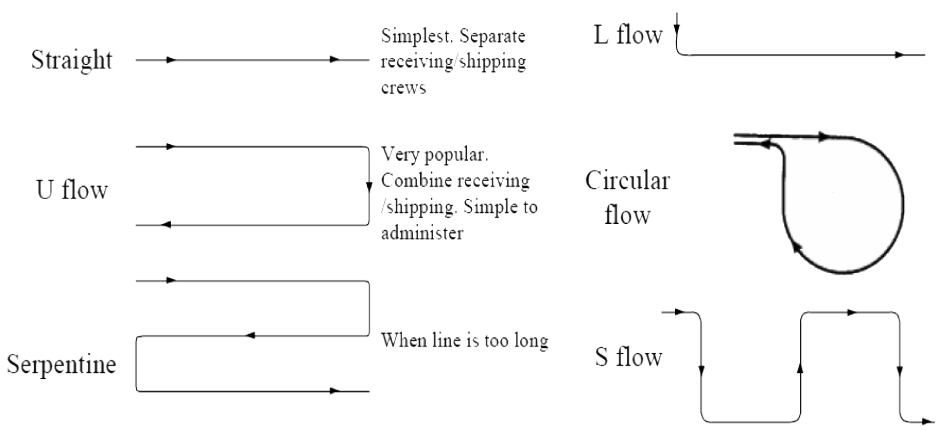

Fig. 1. Examples of layout types.

Table 1
CORELAP and ALDEP preference ratings (Muther diagram) [1]

Code	Degree of importance	Score
A	Absolutely necessary	64
E	Very important	16
I	Important	4
O	Ordinary importance	1
U	Unmportance	0
X	Undesirable	–1,024

ers. The preference ratings (A, E, I, O, U, and X) indicate the relative importance and score of each combination of department pairs (Table 1) [7].

The proposed model is based on implementing the mathematical approaches of systematic layout planning procedure (SLP) and adjacency score (AS) [3]. Input data refers to the number of departments, required areas and proximity between the linked production components and according to a relationship chart (Muther diagram) [1]. The proximity relationships are illustrated in Fig. 2.

CORELAP stands for COmputerized RElationship LAyout Planning and its objective is to create a layout with "high-ranking" departments close together. The assumption of CORELAP is that the department will have a dispatch area and a receiving area on the side of its layout nearest its neighbor. The input data of CORELAP are a number of departments, department areas; relationship chart; and weights for relationship chart. The optional input data are scale of output printout, length to width ratio, and department pre-assignment (only along the periphery of the layout).

ALDEP stands for Automated Layout DEsign Program and is a variation of CORELAP. Its objective is also to create a layout with "high-ranking" departments, but ALDEP has special characteristics of randomness. The input data of ALDEP are length, width, and area of each floor, location and size of restricted area for each floor, scale of layout printout, number of layouts to be generated, number of departments, department areas, relationship chart and minimum allowable score for an acceptable layout.

ALDEP, Automated Layout Design Program, is similar to CORELAP in terms of basic data input requirements and objectives [17]. What sets them apart, though, is that CORELAP uses total closeness rating values to place best department in the middle as opposed to ALDEP placing the departments in the layout randomly in a twisted outline (Fig. 3). This difference is philosophical: CORELAP attempts to generate the best layout, while ALDEP produces many layouts, rates each layout and leaves the evaluation of the layouts to the facility planner [17].

3. Objective function

Process layout is a multidisciplinary area by nature that requires input from different specialists such as civil, mechanical, electrical, chemical, and reliability and control engineers. The layout problem can be defined as allocating a given number of equipment and service in a given land to optimize an objective function that depends on the material handling measure between facilities, subject to a variety of constraints of distances [18,19]. Thus, the objective of the process layout is the most economical spatial allocation of process units and their piping to satisfy their required interconnections. Starting with the full plant flow diagrams, this activity has been associated with the process design stage: the process design should not be declared as done if the plant layout has not been covered. Furthermore, facility layout problems also occur

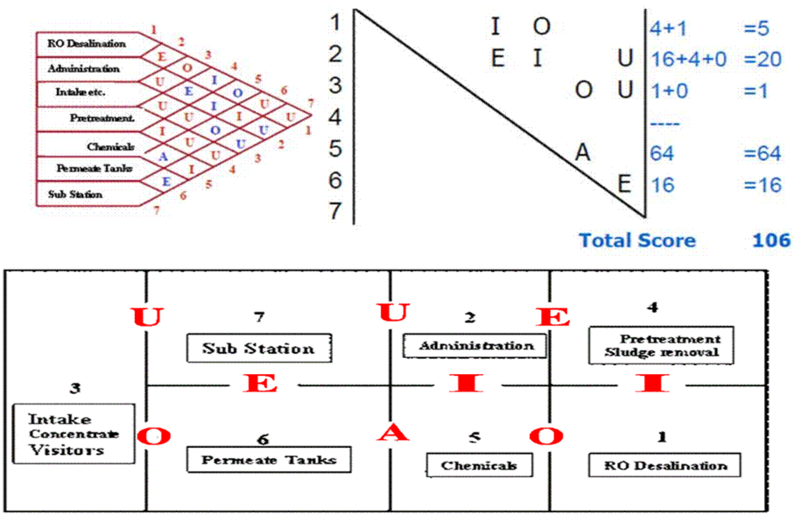

Fig. 2. An example of input data (Muther diagram) and plant layout.

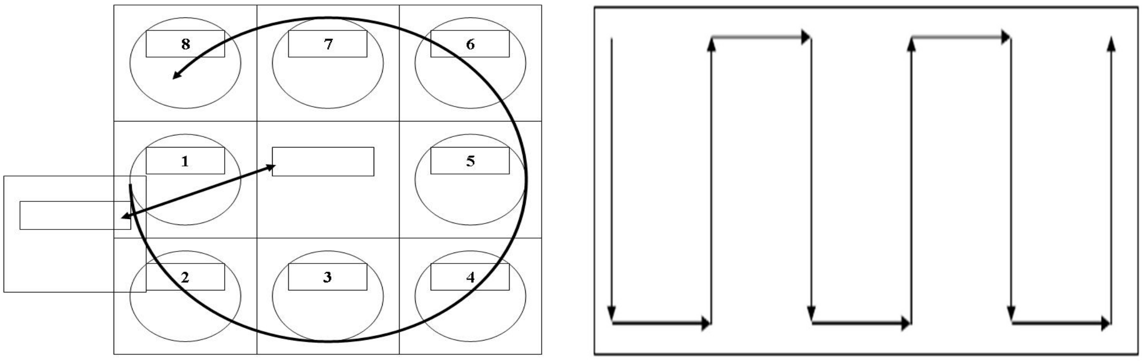

Fig. 3. An example of Corelap and Aldep algorithms output.

if there are changes in requirements of space, workers or equipment [17].

The design process is dependent upon the objectives. Concerning desalination plants, common design objectives include: (1) low cost per cubic meter, (2) short response time, and (3) flexibility. The desalination process plant layout problem can be stated as follows: Given a set of equipment items and their dimensions and the connection costs among equipment items, determine the allocation of each equipment item (i.e. coordinates and orientations) so as to minimise the total connection cost. Due to industrial practice, all equipment items are considered as rectangular shapes with fixed widths and lengths [1].

The layout with lowest materials handling cost (MHC) for most number of scenarios was selected as the most economical layout that minimize permeat cost [6]. Short response time is connected with plant utilization and lean production methodology. In lean manufacturing concept, activities performed in an enter- prise are grouped either as value adding or non-value adding activity and through appropriate actions, the non-value adding activities are eliminated in order to minimise the waste. Similarly in this work, the productive area utilised for various activities/elements are measured as either value adding or non-value adding areas in order to minimise the area utilised for non-value adding activities/elements [5].

Flexibility is one of the most crucial parameters for market survival in today's manufacturing environment. Flexibility can be defined as an ability of a manufacturing enterprise to respond quickly and effectively with little penalty in time, effort, cost or performance to the uncertainties and changes in customer requirements [20]. This manufacturing flexibility can be further categorised into several types, which include volume, modification, expansion, operation, product, process, routing, labour, machine, material handling and others [21].

4. Desalination plant design

The design of seawater desalination plants is a complex and comprehensive topic that covers several disciplines [22,23]. It involves the expertise of civil, electrical, industrial, infrastructure and mechanical engineers, as well as architects, consultants in different areas including public acceptance, managers and chemists [24–26]. The objectives of the plant layout strategy are to meet: (i) economic aspects: minimal capital investments along with reduced operation and maintenance expenses; (ii) satisfying capacity and quality constraints; (iii) minimal environmental pollution; (iv) reduced production times and maintaining high flexibility for unexpected changes; (v) maintaining maximal convenience and safe conditions within the production halls for the workers, and; (vi) efficient use of the available land along with "good-looking" facilities.

The main objective of this work is to present a methodology based on implementing computer aided techniques, for flexible design of seawater desalination facilities layout and incorporates into the design all the above mentioned aspects. Besides these aspects the main production factors include the main desalination membrane unit, the pretreatment stage, coagulation and flocculation, permeate storage, pumping stations, chemical storage units, control center and the administrative and visitor center. The analysis is based on the data production of 125,000 m^3/d [27] in Australia (Table 2).

The proposed model is based on implementing the mathematical approaches of systematic layout planning procedure (SLP) and adjacency score (AS) [3]. Input data (Table 2) refers to the number of departments, required areas and proximity between the linked production components and according to a relationship chart (Muther diagram) [1]. The proximity relationships are defined by Table 1 (A,E,I,O,X) [7] and the two options concerning the preliminary results are illustrated in Fig. 4 (Aldep algorithm) and Fig. 5 (Corelap algorithm).

The computational results indicate that the proposed approach successfully obtains the same or better "quality" solutions than many existing desalination plants (that have straight or L flow shape, Fig. 1). The outcome indicates that the layout produced by the Corelap algorithm

Table 2
Seawater desalination data, 125,000 m³/d (Gold Coast, Australia)

Plant structure	Area, m²
Administrative building	1,050
Substation	660
Pretreatment building	1,925
Flocculation tanks and filters	5,225
Chemical storage area	785
RO building	6,750
Storage tanks (×2)	2 × 1,640

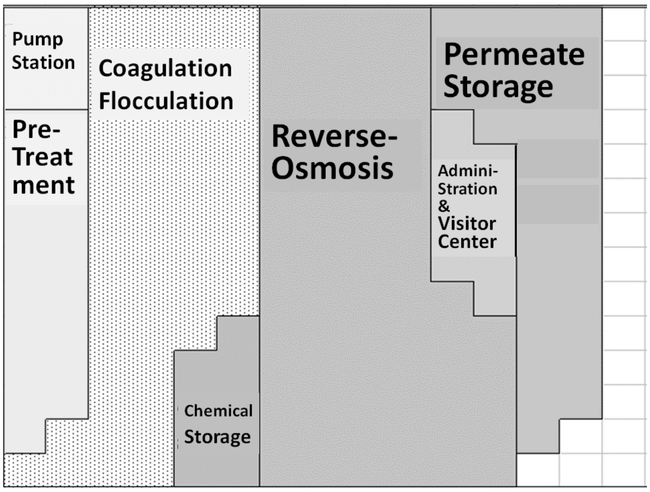

Fig. 4. Aldep algorithm layout output.

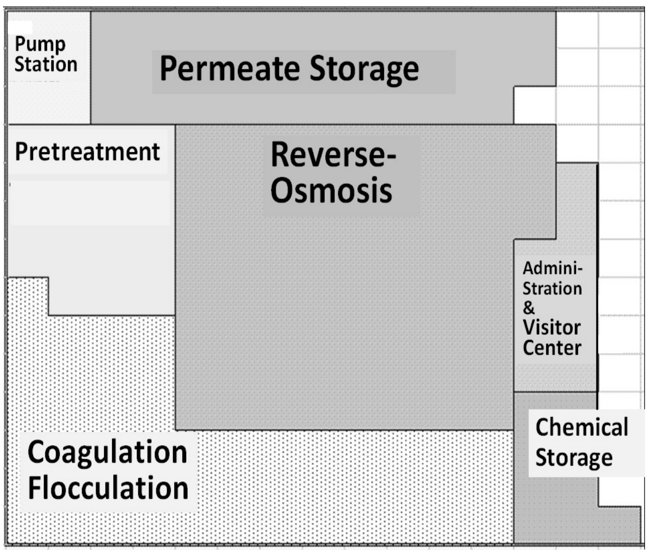

Fig. 5. Corelap algorithm layout output.

results in a low total material handling cost and flexibility regarding disturbance in the future, and helps the water industry to maintain a competitive edge.

5. Discussion and conclusions

In the current desalination plant design, the attention is given mainly to the chemical flow sheet and the layout is based on straight or L shape flow. Optimization of plant design includes a distance-based objective to find the minimum total cost among various lternative facility layouts. In the real world scenarios, the quantitative aspect of the facility layout may not be sufficient; the qualitative factors (relation between equipment) are also something to be considered. This research takes the body of knowledge one step further by combining the quantitative based objective of facility layout with the qualitative or adjacency based objective to better reflect real-world scenarios.

This paper makes two important contributions. First, it presents the ALDEP and CORELAP algorithms, a computer software that are remarkably robust: handle a wide variety of equipment and obtain results competitive with customary methods (straight line or L shape). Second, it provides new insights about desalination plant design: (i) The computation power and accuracy of the computer allows the generation and evaluation of many alternative layouts, (ii) The computer solves each problem on its own merit following objective and systematic procedures and possibility will generate innovative or unusual layouts, (iii) The computer requires an explicit clear problem and objective definition, and (iv) The computer requires a rigorous data preparation.

The computational results indicate that the proposed approaches successfully obtains the same or better quality solutions than former flow sheet based approaches coupled with significant computational savings.

Acknowledgments

This work was supported partially by the SMART (Sustainable Management of Available Water Resources with Innovative Technologies) project financed by the Ministry of Science of the German government [Projektantrag zum BMBF-Förderschwerpunkt, Integriertes Wasserressourcen-Management (IWRM)], by The Beracha Foundation, The Stephen and Nancy Grand Water Research Institute, The Technion, Haifa Israel, The Palestinian-Jordanian-Israeli Project (PJIP) (1996), on Membrane Technology for Secondary Effluent Polishing: From Raw Sewage to Valuable Waters and Other By-Products, and by The Levin Family Foundation, Dayton, Ohio, USA, on Membrane Use for Wastewater Reclamation and the Research Authority of Jerusalem College of Technology (JCT), Israel.

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