RO SYSTEM DESIGN REHABILITATION
PART I: SIZZLING FEED INTAKE MANAGEMENT

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ABSTRACT

The present work recuperates the retrograded performance of seawater RO units when subjected to seasonal sizzling feed intake beyond the design conditions. The gained operational experiences have indicated that when the RO feed temperature increases, the feed pressure must decreases to achieve membrane integrity. In addition, the membrane fluxes increases as the feed temperature increases, under the constraints of maximum allowable manufacturer membrane flux. This results in lowering the operating pressure of the system, and eventually decreasing the system productivity. Therefore, a proposal of an operation at the original system design pressure can be achieved by elevating the permeate backpressure in a manner allowing the system first pass to bring the design pressure, and the system second pass to an elevated pressure. In such case the system productivity increase by about 7%, 13%, 18%, and 27%, for feed temperature increase by 30, 35, 40, and 45^{o}C respectively. This Corresponds to product specific power consumption which gets better from 18.9, 20.1, 21.2, and 23.1 KWh/1000 gallon, down to 18.2, 18.5, 18.6, and 19.1 KWh/1000 gallon. Therefore, the design curves of the amended permeate backpressure system have been obtained. These curves indicate that the proposal is feasible and efficient in restoring the undesirable sizzling feed intake beyond the design conditions, and the system is nearly restoring its recovery condition.

INTRODUCTION

In a previous study, the seawater feed RO preheating system process has been evaluated. In which the basic transport equations describing the system are utilized for determining the performance of the feed preheating process. The authors concluded that the permeate productivity decreases by the increase of the feed temperature. Also, results have indicated that the product's specific power consumption is dependent on the used number of elements. In case of maximum available number of elements, it is found that, the specific power consumption increases by increasing the feed temperature.

In the present work the problem of the undesirable sizzling feed intake beyond the design condition and/or design conditions malfunctioned is handled and resolved. For consistent with previous findings, the same seawater membrane type FT30SW380HR is used to perform such studies [1].

PROBLEM IDENTIFICATION

The author findings are; the ultimate permeator applied pressure radically decreases with the increase of the feed temperature for all feed salt concentrations and for all feed flow rates. Meanwhile, the permeator salt rejection is significantly decreased by the increase of feed temperature. Moreover, the leading membrane in an array has a characterized effect on the array performance passing through the maximum pressure that can be applied. The constraints of the maximum operating parameters of the membrane, e.g. feed temperature, applied pressure, permeate recovery, flow rate, and minimum brine flow rate are contributing the leading element performance [2]. Generally it has been shown that as the feed temperature increases, the feed applied pressure decreases with regard to other operating parameters, principally the leading element maximum permeate flux and recovery. These in turn decrease the system productivity [3].

For a certain feed flow rate, the permeator flux and recovery are determined by the product flow rate. Therefore, the permeate basic transport equation through the spiral wounded RO membrane element is determined by the following equation:

$$Q_P = k_w \cdot S_E \cdot (TCF) \cdot (FF) \cdot NDP$$
$$\& \, NDP = \left[P_f - \frac{\Delta P_{fc}}{2} - P_p - \pi^{-}_{fb} + \pi^{-}_{p} \right] \tag{1}$$

where

NDP=net driving pressure, *psi.*
Q_P = product (permeate) flow, *gpm.*
K_w = membrane permeability at 25 °C, as a function of the average concentrate pressure, *gfd/psi (gallons / ft^2 / day / psi).*
S_E = membrane surface area, ft^2.
FF = membrane fouling factor.
P_f = feed pressure, *psi.*
P_P = permeate backpressure, psi.
ΔP_{fb} = feed-brine flow pressure drop through the membrane, *psi.*
π^{-}_{fb} = average feed brine osmotic pressure, *psi*
π^{-}_{p} = average product osmotic pressure, *psi*

To obtain a constant membrane limiting flux for the case of increased feed temperature, i.e. constant Q_P, can be achieved by maintaining the right hand side of the equation constant in spit of increasing the term TCF. This can be achieved by decreasing the NDP. Actually decreasing of NDP leads to a decrease of the system productivity, as mentioned before. Consequently, as the feed temperature increases, the system productivity decreases. Therefore, in the present work, a proposal for resolving this problem is carried out and assessed.

RO SYSTEM DESIGN REHABILITATION

The membrane TCF term increases as the feed temperature increases. According to the abovementioned equation the same membrane flux, can be maintained be decreasing the NDP. The NDP consists of five terms. The only terms which can be varied (for the same feed flow rate and concentration) are the feed pressure P_f, which has a positive value, and the permeate backpressure P_P, which has a negative value. Therefore, in the first pass of RO system, the feed pressure can be increased to the limiting membrane value. Meanwhile, the permeate backpressure can be increased to the pressure vessel maximum operating pressure value. This can also be achieved by increasing the permeate pressure passing through a throttling valve, to maintain the desired NDP. For the time being, the NDP of the second pass of the RO system will increased by the value of the elevated permeate backpressure in the first pass, as there is no throttling valves on the permeate second pass, as shown in Fig. (1).

The data of the maximum permeate backpressure for FilmTec pressure vessel P_P, as an example, is a function of the feed temperature T_f, which can be correlated with a maximum error of ± 0.5 % as follows,

$$P_P = 514.714 - 9.257\, T_f + 0.02286\, T_f^2 \tag{2}$$

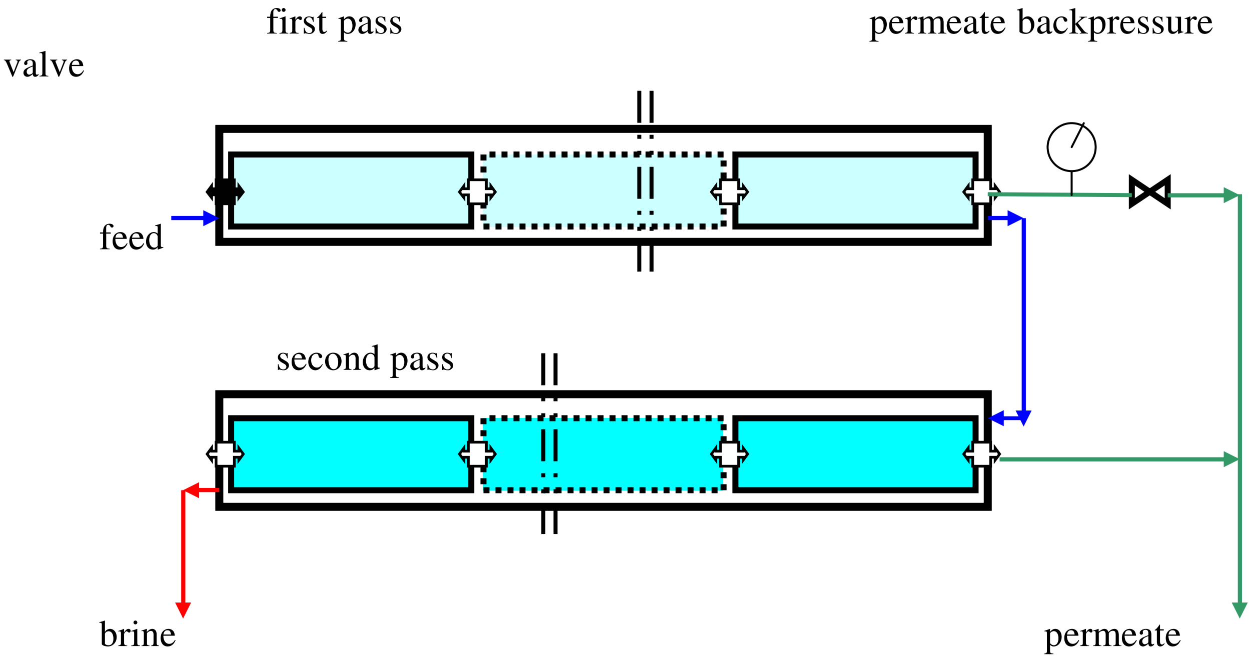

Fig.(1) Schematic layout of RO system with a proposed backpressure permeate valve.

The application of Equation (2) is constraints by the manufacturer membrane working maximum pressure. It is worth mentioning that the maximum working feed pressure of the used membrane FT30SW380HR, is 1000 psi.

RESULTS AND DISCUSSIONS

The restoration proposal of the aforementioned system is achieved by the appraisal of the feed preheat for the RO system, [2], a computer program for the RO system used to fit the recent permeate backpressure parametric analysis. In each case of the feed temperature increasing variations (the original RO system design feed temperature at 25^{o}C case), the sizzling feed intake cases are studied with and without the amended permeate elevated backpressure cases.

1. Effect of Elevated Backpressure on Individual Elements

Figures (2, 3, 4, and 5) demonstrate the effects of elevating pressures on the individual elements performance at 30, 35, 40, and 45 ^{o}C, respectively. In each figure, the original RO systems designed that are at 25 ^{o}C, together with the sizzling feed intake with and without the amended permeate backpressure are illustrated. The original design of the RO system contains two passes, the first one contains seven elements per pressure vessel, meanwhile the second pass elements are varied according to the feed and osmotic pressures. In each case, the operating parameters are kept so that; the feed flow rate, the feed salt concentrations and the membrane flux have the values of 45 gpm, 40 g/l, and 18 gfd, respectively.

Figure A depicts the applied pressure aviations to each element series position, at the original design, sizzle feed intake, and the amended increased pressure via the elevated back-permeate pressure. It is clear that for sizzled feed temperatures, the feed pressures must be lowered in order to maintain the membrane exact correct operating conditions. These pressures are, 983, 933, 891, 857, 829 psi for feed temperatures of 25, 30, 35, 40, and 45 ^{o}C respectively. Meanwhile, for the proposed system, the permeate back-pressures in the first pass are increased to 50, 92, 126, and 154 psi for sizzled feed temperatures of 30, 35, 40, and 45 ^{o}C respectively. Consequently, the individual elements parameters are varied. Figures B, C, D, E, and F are describe the variations of the productivity, product salt concentration, membrane salt rejection, element permeate flux, and element recovery, are given in Figs. B, C, D, and E respectively.

2. Effect of Elevated Backpressure on accumulative array Elements

For system operation restoration, the aforementioned figures are incorporated to present the variation of the accumulative arrays parameters with the positions of the element series. These parameters are represented and pointed up in Figs. (6, 7, and 8). Fig. (6A, to 6D) depicts the accumulative productivity and the net driving pressure (NDP). These are given for different feed sizzled temperatures, at any element series position, at normal system operation and after the restoration by the amended permeates backpressure system. It can be noticed from these figures, that the number of elements for the system decreases as the feed temperature increases. Meanwhile, for the amended permeate backpressure system, the number of elements is nearly maintained as the original design. It can be observed from Fig. (6A), that the system productivity is degraded for the sizzler feed from 22.4 gpm at 25 °C, to 20.9, 19.2, 18.0, and 16.2 gpm for the feed temperatures of 30, 35, 40, and 45 °C, respectively. Meanwhile, Fig. (6B) shows that, it is restored by the amended permeate backpressure system is restored to 21.9, 21.4, 21.2, and 20.6 gpm, for the same abovementioned temperatures, respectively. This can be interpreted by increases of the NDP in the second array to about 160 psi, as shown in Fig. (6D). The increase in the amended permeates backpressure system productivity, is associated with the system recovery increase as shown in Fig. (7D). Also, it results a slight degradation of product salt concentration to an acceptable value below 0.9 g/l as shown in Fig. (7B), and salt rejection as shown in Fig. (8B). Accordingly, a slight decrease in system average membrane flux is accomplished due to the increased number of membranes as shown in Fig. (8D).

3. Permeates Backpressure System Performance

The performance of the amended permeate backpressure system, can be determined through the comparisons between the original design normal operation (at 25 °C) with the declined operation of the original design by feed sizzled temperatures, and the amended permeate backpressure system operation restoration. These comparisons are depicted in Fig. (9). This figure includes the feed pressures, available number of elements, average NDP, system productivity, system average flux, system recovery, permeate salt concentration, system salt rejection, and the permeate specific power consumption, at different feed temperatures, for the abovementioned three cases.

It can be noticed from Fig. (9A) that the feed pressure must be decreased as the feed temperature increases. This can be interpreted, as the feed temperature increases; the membrane fluxes increase under the constraints of maximum allowable manufacturer membrane flux. This result tends to lower the operating pressure of the system, to achieve membrane integrity. Therefore, the proposed backpressure system restores almost the original pressure, allowing the increase of the available number of elements (as shown in Fig. (9B)). However, it is tends to decrease the NDP of the system (as shown in Fig. (9C)). Also, the increased feed pressure allows more system productivity and recovery (as shown in Figs. (9D and 9F)). This in turn decreases the specific power consumption. It is worth mentioning that lowering the average system (as shown in Fig. (9E)) tends to decrease the system salt rejection (as shown in Fig. (9H)), and to degrade the product salt concentration (as shown in Fig. (9G)).

Therefore, the present proposal brings the system pressure to the original system design value. This enable the system productivity to increase from the sizzling feed conditions at 20.86, 19.23, 18.01, and 16.17 gpm, up to 21.93, 21.64, 21.25, and 20.59 gpm, for the temperature increases to values 30, 35, 40, and 45 °C, respectively.

Correspondingly, the product specific power consumption [4] is get better from 18.9, 20.1, 21.2, and 23.1 KWh/1000 gallon down to 18.2, 18.5, 18.6, and 19.1 KWh/1000 gallon (with a system brine power recovery of 60 % for all cases). Thus, the amended permeate backpressure system increases the sizzling feed conditions productivity by 5.1 %, 12.6 %, 18 %, and 27.3 % corresponding to feed temperatures of 30, 35, 40, and 45 °C, respectively. Therefore, the amended permeate backpressure system proposal seems quite feasible and efficient in restoring undesired elevated feed temperatures.

REFERENCES

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[3] Karameldin, A., "Seawater RO preheating appraisal, Part 1: system performance", IJND V2 N2, 2005.

[4] U.S. Filter Blue Sheet, "Spiral wound reverse osmosis systems", United States Filter Corporation, 1994.

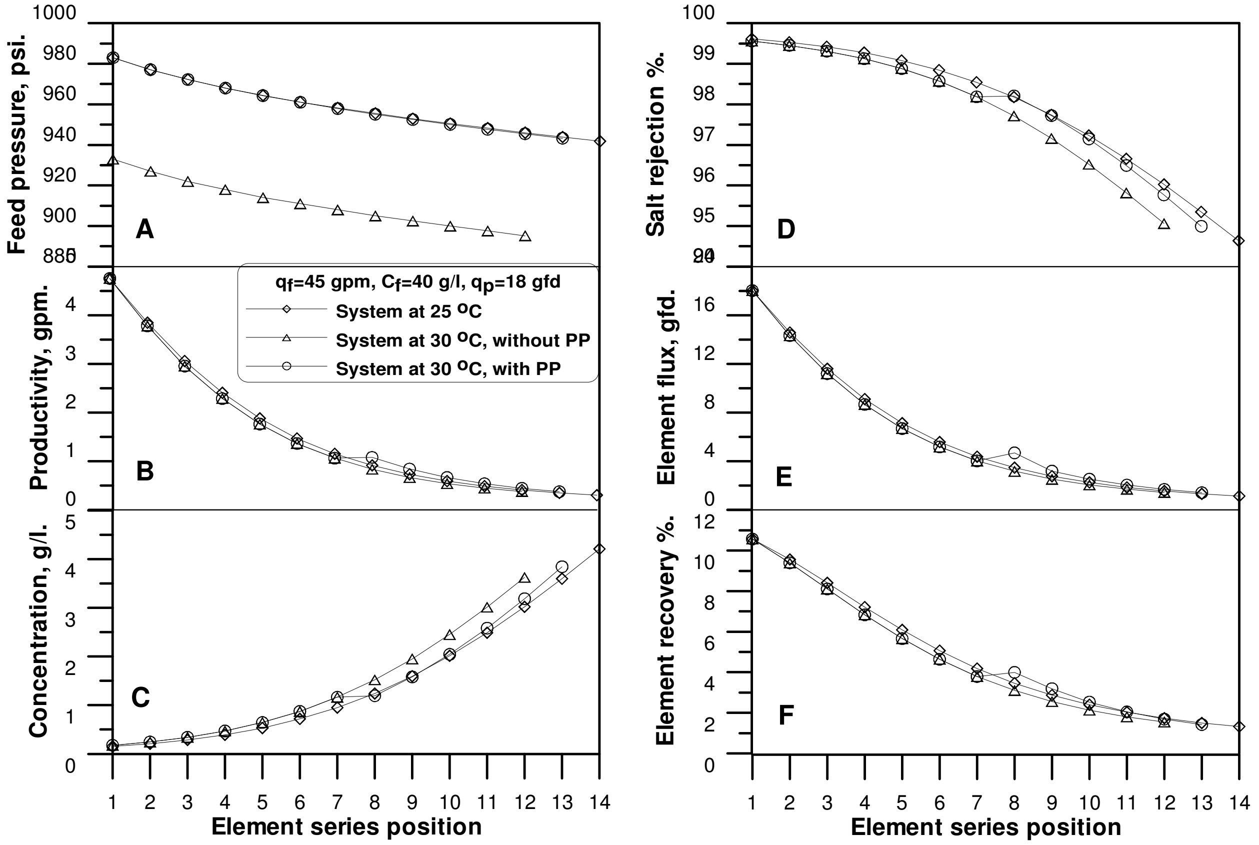

Fig.(2) Effect of elevating pressure on individual elements performance at 30 °C.

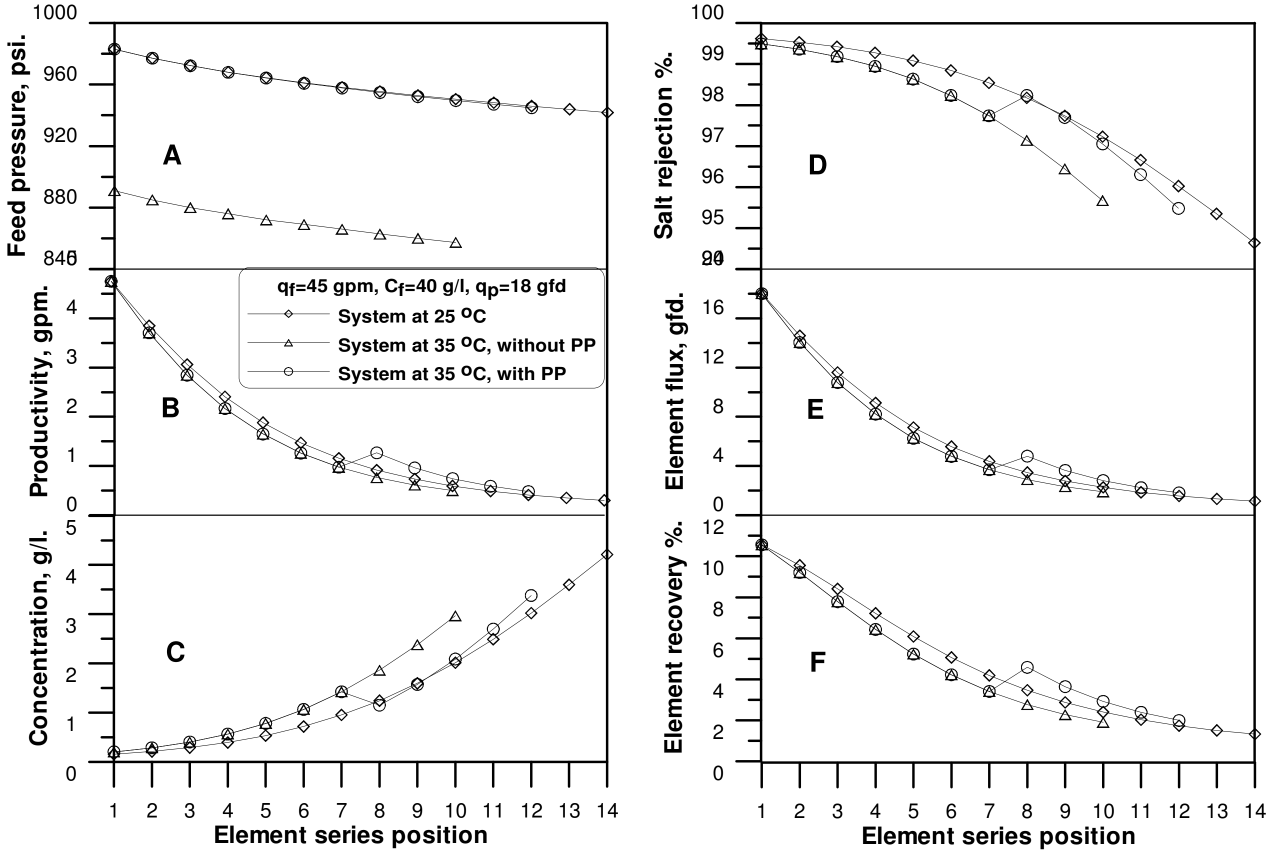

Fig.(3) Effect of elevating pressure on individual elements performance at 35 °C.

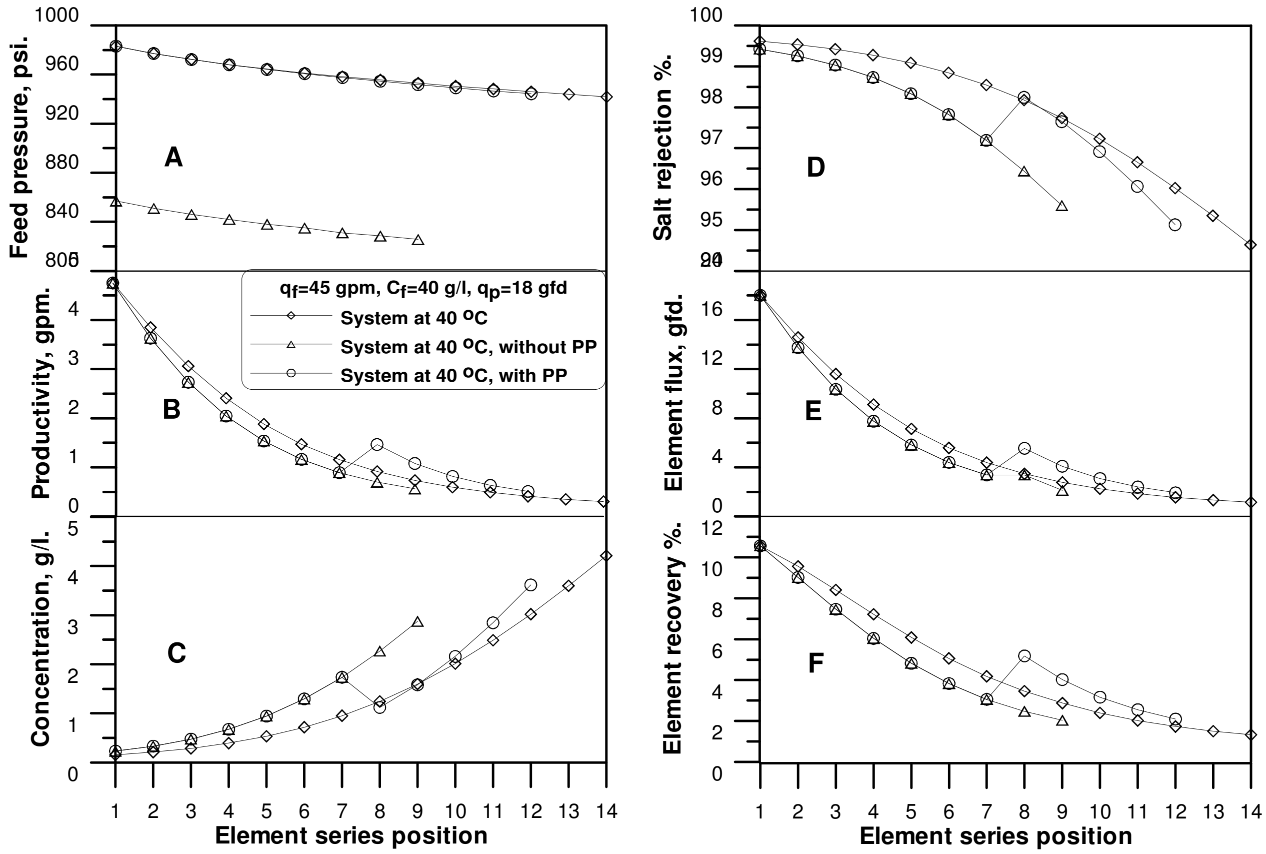

Fig.(4) Effect of elevating pressure on individual elements performance at 40 °C.

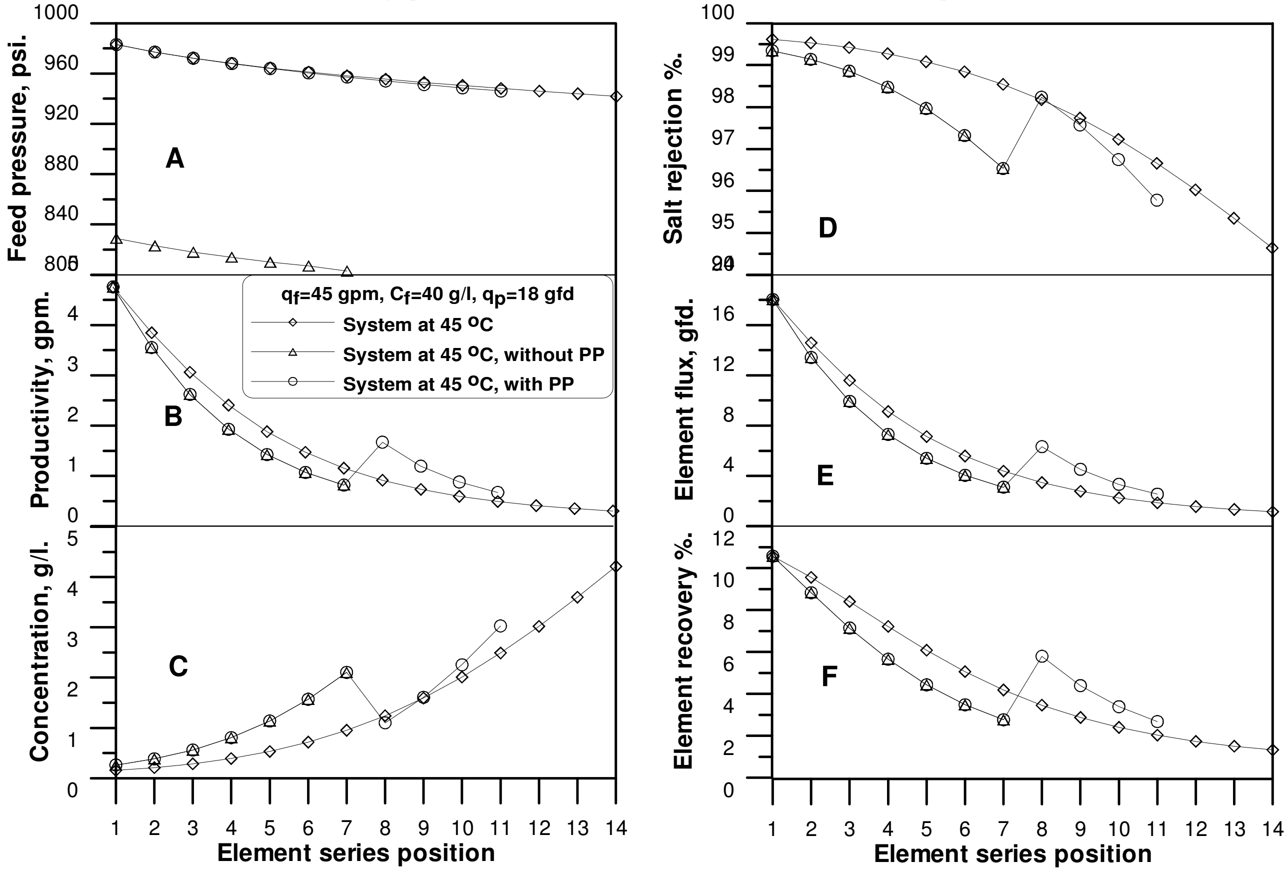

Fig.(5) Effect of elevating pressure on individual elements performance at 45 °C.

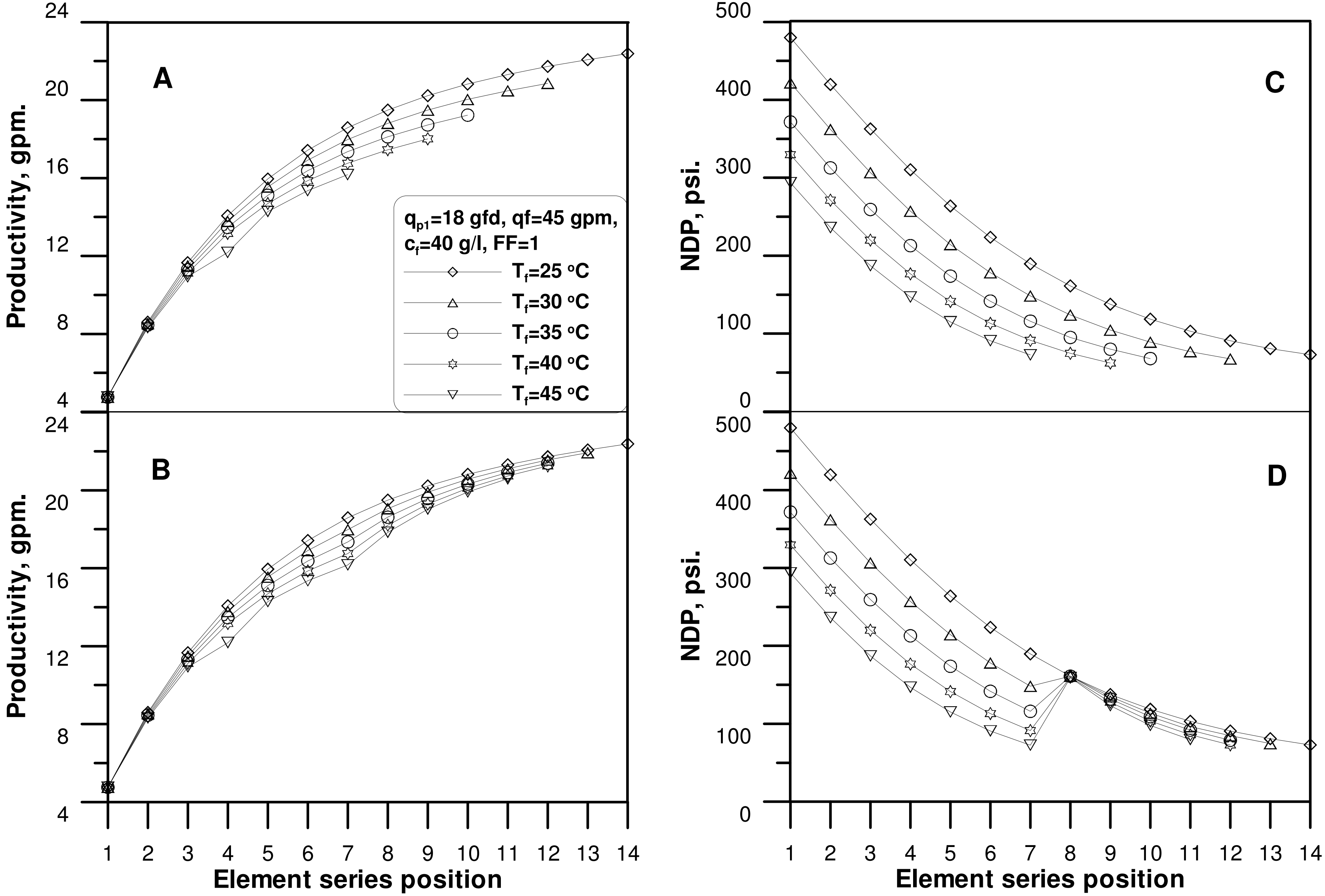

Fig.(6) Variations of array accumulative productivity and NDP by system pressure invrease.

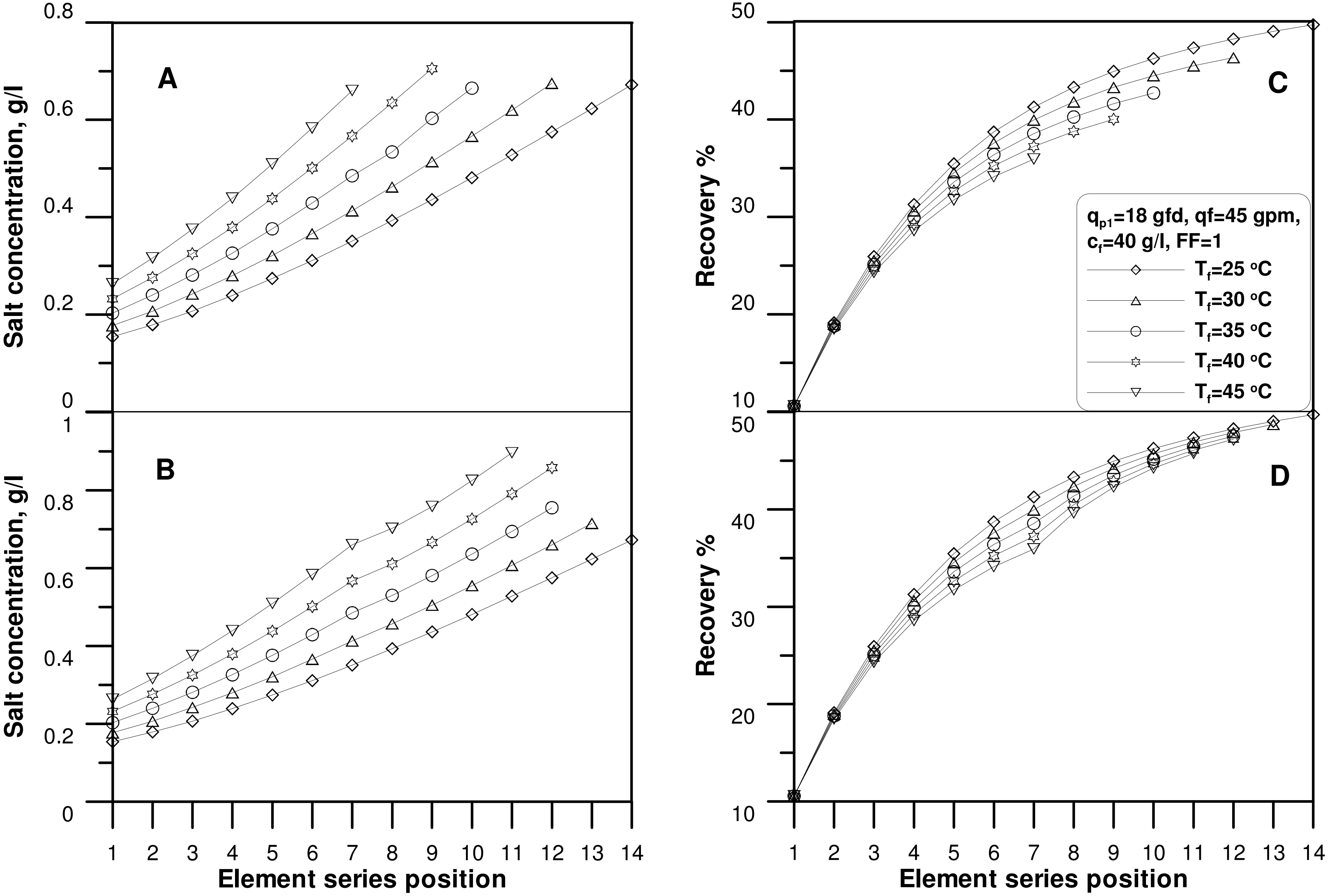

Fig.(7) Variations of array accumulative permeate salt concentration and recovery by system pressure increase.

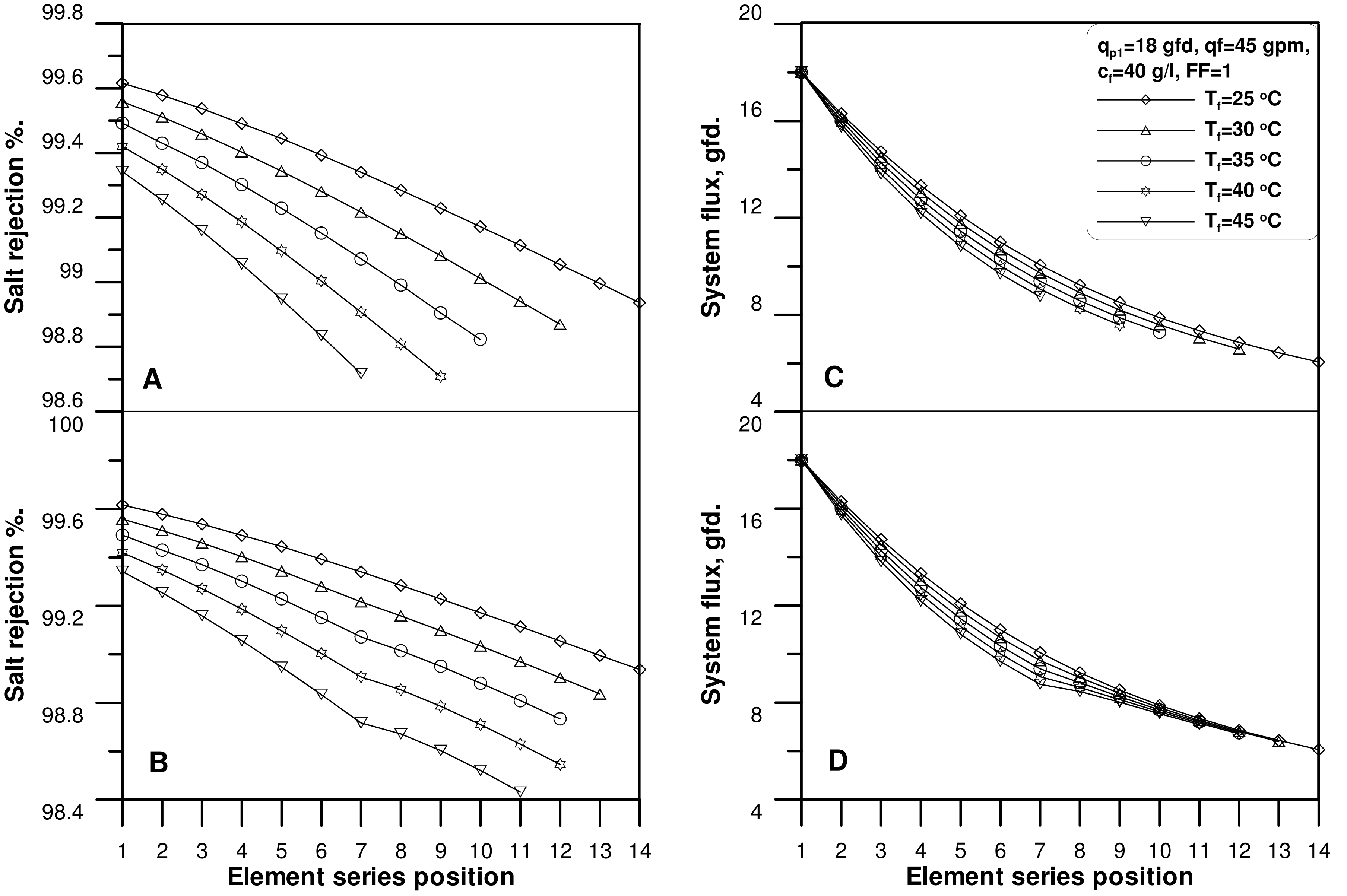

Fig.(8) Variations of array accumulative salt rejection and membrane flux by system pressure increase.

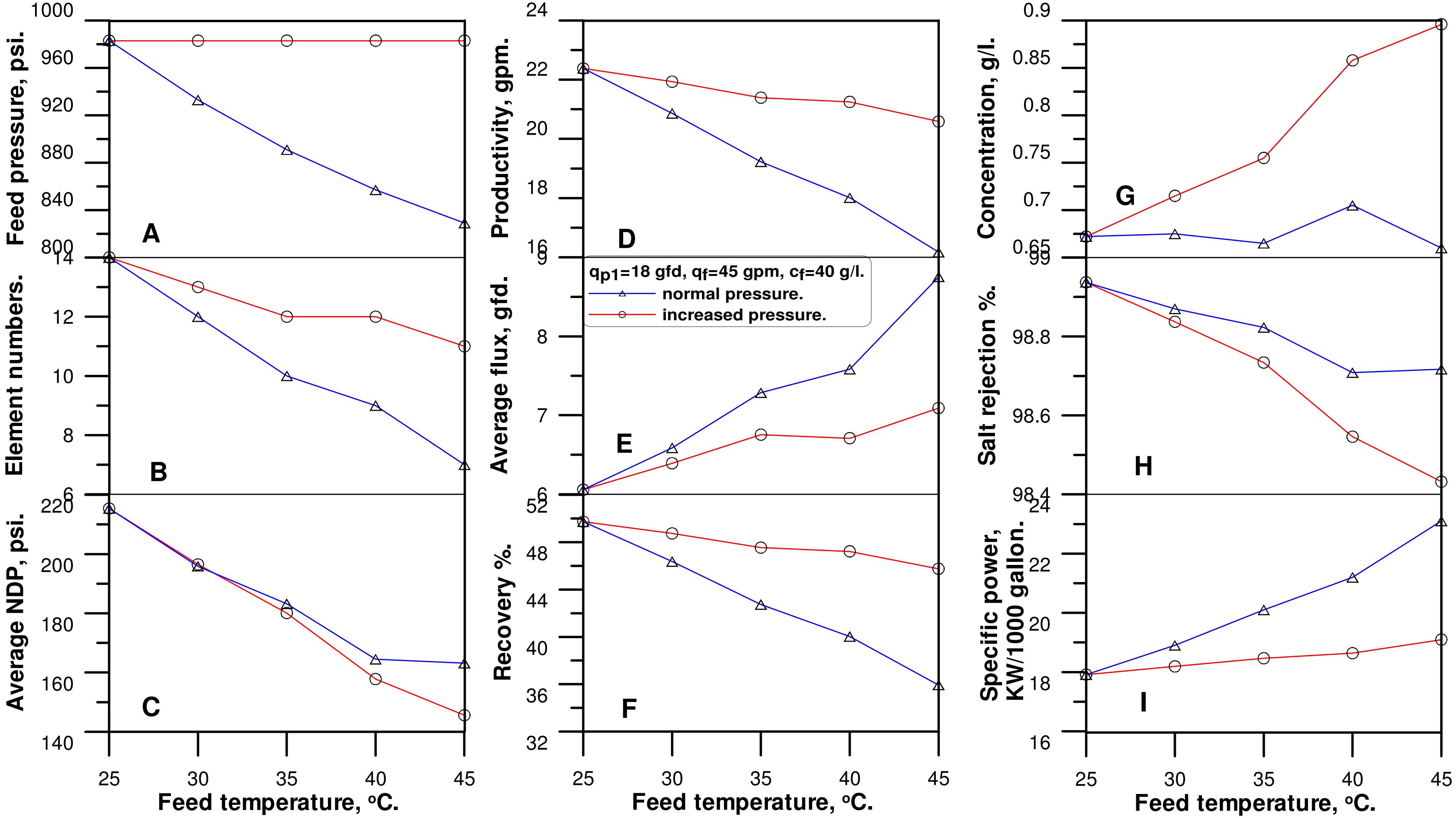

Fig.(9) Effect of elevating permeate backpressure on array performance at different operating temperatures.