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Modeling of Salt Gain Rate in the Herring (*Clupea harengus*) During Brining Process

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ABSTRACT

Despite the presence of food processing technologies, there is a growing need for data analysis. The possibility of controlling time, cost and quality is attainable by employing predictive models. Thus, the present study was conducted to determine whether the Peleg equation could be used to simulate the rate of salt gain during brining herring at a specific brine concentration and brine retention time. In addition, a novel model was implemented to predict salt uptake at various brine concentration levels, even those that were not tested. For bringing solution concentrations of 10%, 15%, 20% and 25% at the same arrangement, the resulting Peleg constants via a Peleg model (MPC) recorded values of K_1 (rate constant) and K_2 (capacity constant), with 14.21069, 14.70289, 11.00787, and 8.800355 g/100g and 0.212660574, 0.11740342, 0.118972, and 0.115634 g/100g, respectively. Fitting these models yielded a significant correlation (R^2) and good accuracy (0.93,0.96, 0.93, 0.94). After being combined with a peleg (MPC) model, a polynomial model (IPM) that had previously calculated peleg constants for various brine concentrations demonstrated the capacity to predict various salt uptakes under those various brine concentrations when combined with peleg model equation, with correlation (R^2) values of 0.926621, 0.964524, 0.941048, and 0.958703, respectively. The models provide accurate predictions for salt uptake, advancing the cost, time, and quality of the herring industry.

INTRODUCTION

Herring is traditionally preserved via salting, which has been done for millennia in the nations of North Europe. Smoked fish process is one of the biggest fish industry in Egypt, which is mainly based on salted herring (*Clupea harengus*). Smoked herring is produced in Egypt from the imported (usually from The Netherlands) frozen herring fishes. Smoked herring is a very popular traditional fish product widely consumed in Egypt **(Birkeland *et al.*, 2005)**. Variation in salted herring products result from variety in salting techniques, salt concentrations and maturing times **(Nielsen, 1995)**. Nonetheless, it is widely used as a transitional stage in the preservation process **(Rodger *et al.*, 1984; Karl *et al.*, 1995)**. The fact that a water transfer is started as a side consequence of the salt intake is common to all these various salting processes **(Gallart-Jornet *et al.*, 2007)**.

Comprehending of brining kinetics is crucial for manufacturing processes that aim to create new products, as well as modifying the conditions of on going processes while improving control over other process variables such as brine concentration and immersion time in addition to brining velocity. Traditional mathematical models rely on the penetration equation and the apparent diffusion coefficients "DAP" to define mass transfer during osmotic dehydration **(Chiralt *et al*., 2001; Telis *et al*., 2003; Mujaffar & Sankat, 2005; Volpato *et al.*, 2007)**. "DAP." is described in this way as an empirical parameter that is based on penetrative and non-penetrative methods for regulating salt uptake by meat samples brined in a saline solution. Although the numerous methods of mass transference on the food material to osmotic dehydration are not described by the penetration equation, it is a very positive development to empirically represent these processes. Food engineers and scientists have employed analytical manipulations for the penetration equation for the traditional geometries and well-defined boundary and start up situations **(Chiralt *et al*., 2001; Telis *et al*., 2003; Mujaffar & Sankat, 2005; Volpato *et al.*, 2007)**.

Only for regular geometries can salt penetration equations have a mathematical solution. Numerical techniques are mostly used to solve non-regular geometry. It is therefore necessary to use additional empirical models. It has been observed that simple empirical models can describe mass transfer in foods exposed to osmotic treatment without having any geometric restrictions **(Azuara *et al*., 1992; Corzo & Bracho 2006a, b; Schmidt *et al.*, 2008)**. Empirical models, which have an exponential distribution and rely on a Weibull-type equation have been used to depict food osmotic dehydration rates and air dehydration rates **(Machado *et al*., 1999; Cunha *et al*., 2001; Corzo *et al*., 2008; Garca-Pascual *et al*., 2006; Deng & Zhao, 2008)**. Although there aren't many studies on applying these empirical models to describe the moisturising and drying processes on beef slices, they do exist. Models were implemented in order to characterize the moisture leaking rate and predict the balanced solutes concentration in apples **(Kaymak-Ertekin & Sultanoglu, 2000)**, fish **(Mujaffar & Sankat, 2005; Corzo & Bracho, 2006a)** and chicken meat **(Schmidt *et al.*, 2008)**. A modest application of the empirical model was conducted in the study of **Azuara *et al.* (1992)**. **Peleg (1988)** applied a binary- parameters model to project the moisturizing rate by powdery milk and rice grains. This empirical model was applied to model the uptake curves of various foods **(Abu-Ghannam & McKenna, 1997; Maskan, 2001; García-Pascual *et al.*, 2006)**. Additionally, this model was used to determine the moisture leaking rates of fruits, vegetables **(Palou *et al.*, 1994; Park *et al.*, 2002; Azoubel & Murr, 2004; Khin *et al.*, 2006; Cunningham *et al*., 2007)** and fish **(Corzo & Bracho, 2006b; Corzo *et al.*, 2007)**. Foods were processed by osmotic (brine or sugar or acid) solutions, giving the capacity to represent water losses and solid intake as well as the physical-chemical and sensory properties of the processed fish in the simplest manner. These models gave benefits of the mass transport phenomena seen during the process since they overlook the internal barrier to mass transfer.

The objectives of this study were to: (1) determine whether the Peleg equation could be used to model the rate at which salt is gained upon brining herring at a particular time and under limited variables; and (2) applying novel model to predict salt uptake at various brine concentration levels, even those that were not tested.

Nomenclature

X_i	The salt content (g/100g) at brining time t (h).
X_{0i}	The initial salt content.
k_1	The constant (the Peleg rate constant) (h (g/100g).
K_2	Peleg capacity constant K2 ((g/100g).
(X_E)	Equilibrium salt content.
X_{exp}	The experimental data
X_{pre}	The values predicted by the model
n	The number of data pairs.
P.E.V.	Predicted equiliprium value.
Con.	Concentration.
(MPC)	Modified peleg calculations.
(IPM)	Innovative Predictive model.
(AC_1)	Advanced constant 1.

MATERIALS AND METHODS

1.1. Raw material

Frozen herring fish (*Clupea harengus*) were obtained from Plagia Company (Faro Islands, Norway) and stored under -20°C by an import company (EL NASSER). The fish caught area was FAO 27. The fish specimens were caught between October and December 2021, with length and weight composition of 25– 30cm and 300± 33g/ fish, respectively. Care was exercised to select fishes with the same thickness to minimize the effect of weight & thickness variation on the experimental data.

Food grade dry salt was bought from Syrian Egyptian Company, Port Said Governorate, Egypt.

1.2. Experimental design

Fish thawing was done using air blast blowers for 24 hours until the fish core temperature reached -2° ±2°C. The sufficient weight of herring was used to conduct each experiment in duplicate. The same fish thickness and weight were selected to carry out the experiments in Port Said Star factory, Port-Said Governorate, Egypt.

1.2.1 *Salting conditions and procedures*

Brining technique was adjusted from standard industrial practices. Thus, the whole herrings were retained in plastic containers with salt brine solution (NaCl) (25%, 20%, 15%, or 10%) at a ratio of 1:1.3 (w/v) for fish to brine. Brine was prepared by dissolving

10, 15, 20, 25g of salt (Food-grade salt per 100mL of water, which was used as a stock solution for brines. A mesh was used to retain the fish immersed under brine solution.

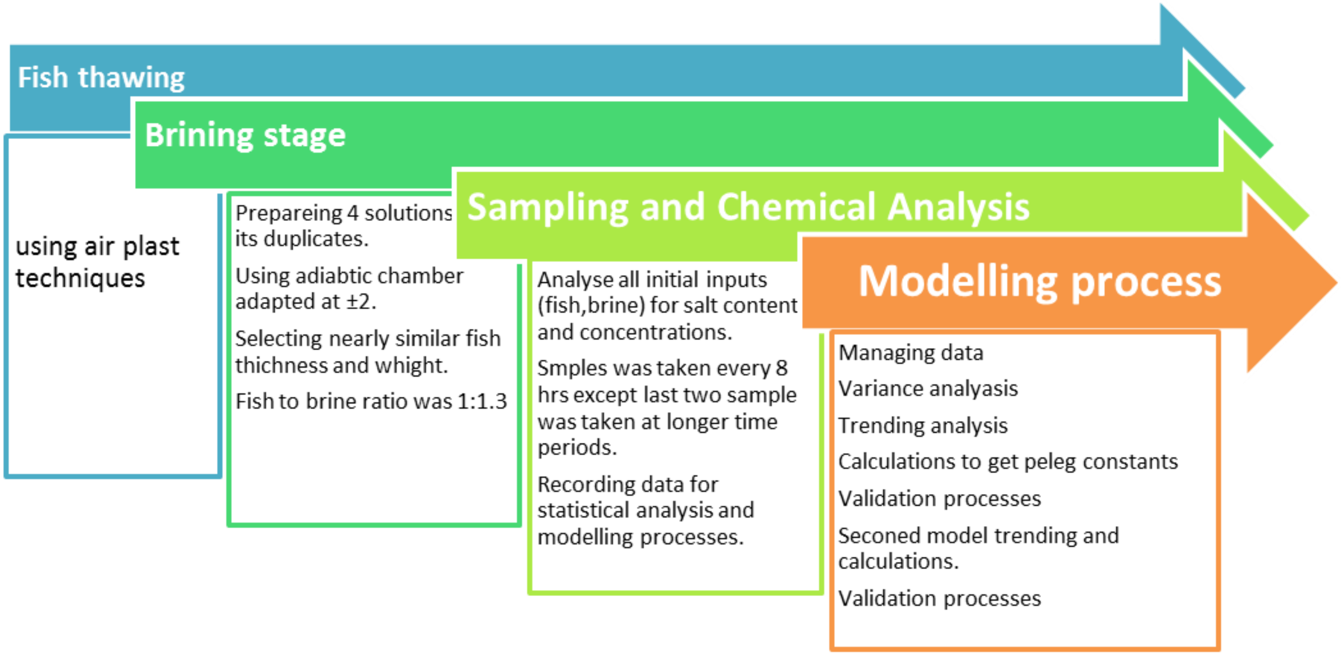

Fig. 1. Experimental stages for thawing, brining, chemical analysis and modelling process

The fish individual was wholly covered with brine, thus all surfaces were in contact with the salting medium. The salting procedure was carried out at a temperature ranginging from 0– 2°C, and all batches were maintained in adiabatic chambers to maintain temperature within the experimental limits. Brine concentration and its samples were put in the containers and left for 160 hours, except for the last two samples, which were taken after time readings of 112-160. Samples were taken out of the bathing medium every 8 hours. At each sampling location, samples were extracted together with an equal weight of brine solution in order to maintain a fish-to-brine ratio of 1: 1.3. Then, samples were rinsed under running water to eliminate any surplus salt crystals, and salt analysis was performed for each sampling location.

1.3. Fish analysis procedures

1.3.1. Determination of salt

Each salted fish was examined to ascertain its salt content by precisely dispensing 5g of the minced material into a 250ml- conical flask. A volume of 100ml of boiling distilled water was slowly added for five to ten minutes to be soaked in random swirling. 2ml of potassium chromate solution was added after reaching a temperature of 50°C followed by well stirring. An amount of 25g of calcium carbonate was added and stirred well, then titrated with normal silver nitrate solution while continually rotating, allowing the color to persist in a brownish color for 30 seconds. After that, the blank test was performed without the sample material, using the same amounts of all reagents. The highest variation did not exceed 0.02 percent of sodium chloride **(IS:3507-ISI, 1966)**.

$$sodium\ chlorid, percent\ by\ wieght = \frac{5.85 * \mathrm{N(V1 - V2)}}{\mathrm{W}}$$

Where;
N= Normality of silver nitrate solution
V_1= Volume of silver nitrate solution
V_2= Volume of silver nitrate in the blank titration
W= Weight in gram of sample

1.3.2. Determination of fat content (Soxhelt method)

According to **AOAC (2007)**, the salted herring samples were dried at 105°C for about 3hrs for moisture determination. After drying, 5 g of dried samples was extracted with petroleum ether (40-60°C) using Soxhlet apparatus for fat determination **(AOAC, 2007).**

1.4. Predictive Model calculations

1.4.1. Predicting salt gain rate at each of (10-15-20-25) % levels separately

Peleg model. Peleg (1988) proposed the following binary-parameter equation to define the mass transfer kinetics that approaches to equilibrium asymptotically:

$$Xi = \mathrm{X0i} \pm \frac{\mathrm{t}}{\mathrm{k1+k2t}} \text{............ (1)}$$

In Eq. (1), ‘‘±’’ becomes ‘‘+’’ if the process is salt gain and ‘‘–’’ if the process is salt loss; According to this model, X_i is the salt content (g/100g) at brining time t (h); X_{0i} is the initial salt content; the constant k_1 (h (g/100g) (the Peleg rate constant) is related to mass transfer rate at the beginning of the salting process; the Peleg capacity constant K_2 ((g/100g) relates to maximum achievable salt content, and $t = t_0$, according to Eq. (2):

$$\frac{dXi}{dt} = \pm \frac{1}{\mathrm{k1}} \text{............ (2)}$$

As t →∞, Eq. (3) gives the relation between equilibrium salt content (X_E) and K2, being $X_i = X_E$ i (Eq. (3)) →

$$\mathrm{XE} = \mathrm{X0i} \pm \frac{1}{\mathrm{k2}} \quad \text{............ (3)}$$

1.4.2. Novel modification and approximations of k_1 and k_2 constants calculation method

By plotting. log v (v=rate of reaction=salt uptake/time) vs log c (C=salt uptake) then slope and intercept from linear equation of the curve are taken to get log (k_1), log (k_2) **(BOEKEL, 1996)**, to get k_1 and k_2, the anti-log of log (k_1, k_2) was determined. To get the best model fit to the original data and reducing sum squares of errors of predicted data, excel solver was used for the mathematical solving of the two factors. The data originated from these approximations and modifications marked by MPC were the modified peleg calculations.

The key benefit of the Peleg model is to shorten the time by expecting salt absorption kinetics of foods including equilibrium salt content (Eq. (3)), using short-time experimental data **(PELEG, 1988; TURHAN *et al.*, 2002)**.

1.4.3. Novel predicted model for salt uptake under different brine concentrations and times

Our assumption was about having a good prediction for salt uptakes under different brine concentrations need a good relationship between constants of K_1 (rate constant), K_2 (capacity constant) and the values of experimental concentrations. This suggestion was applied by discovering the relation between k_1 for every concentration from the previous analysis, which gave us a model formula that gives prediction about k1 at different concentrations then applying validation process. By applying the same data processing for $K_{2,}$ we got $K_1$and K_2 for different concentrations even if they were not tested in the experiments. The afore- mentioned models were merged together to get salt uptakes at different times and concentrations.

2. Statistical analysis

Analysis of variance was conducted to judge the ability to obtain data in a simple linear regression model. The fitting of the model to the experimental data was performed by regression analysis using Microsoft Excel 2010 and IBM SPSS Statistics 23.0.

The determination coefficient (R^2, Eq.4) and root mean square error (RMSE, Eq.5), sum of square error (SSE, Eq.6), total sum of squares (TSS, Eq.7), residual analysis (difference between predicted and experimental data values) were used to evaluate how fit the model was to the experimental data while using a paired- sample t-test for comparing means of different models modifications with experimental data.

$$R^2 = 1-(SSE-TSS) \ldots\ldots\ldots\ldots (Eq.4).$$

$$RMSE = \sqrt{\frac{SSE}{n}} \ldots\ldots\ldots\ldots\ldots\ldots (Eq.5)$$

$$SSE = \sum_{i=1}^{n} (X_{exp,i} - X_{pred,i})^2 \ldots\ldots\ldots (Eq.6)$$

$$TSS = \sum_{i=1}^{n} (X_{exp,i} - \mu_{exp,i})^2 \ldots\ldots\ldots (Eq.7)$$

Where; $X_{exp,i}$ and $X_{pred,i}$ are the experimental data and the values predicted by the model, respectively, and n is the number of data pairs.

RESULTS AND DISCUSSION

Fat content of herring at the beginning of winter season ranged between 7% to 10%, which agrees with the nutrient facts on fish cartoon label and the records of **Lovern *et al.* (1937)**.

Fig. (1) shows a variety of brine concentrations and time periods used to illustrate the dynamics of salt diffusion in brined herring bodies. Initial herring salt content after thawing (before brining process) ranged between 0.1 and 0.4%. With each brine concentration, a gradual increase was detected in the salt uptake by the fish meat with the progress of time. At the same salting period time, the percentage of salt uptake was increased as the salting brine concentration increased. The whole fish brined in 10% brine solution showed the lowest salt absorbed due to the weakness of solution strength under low temperature. It's proven that skin acts as a strong natural barrier against salt penetration **(Rodger *et al*., 1984; Sakai & Suzuki, 1985; Ravesi & Krzynowek, 1991; Gallart-Jornet *et al.*, 2007)**. Other studies have found that salt uptake was not specifically inhibited by the skin itself but by the fat layer beneath the skin **(Rodger *et al.*, 1984)**. **Laub-Ekgreen *et al.* (2019)** believed that, the salt uptake behavior is nearly undistinguishable for two salting conditions 16 & 26%. Conversely, the diffusivity constant for the 16% brine is lesser, which looks somehow unpredicted **(Laub-Ekgreen *et al.*, 2019)**.

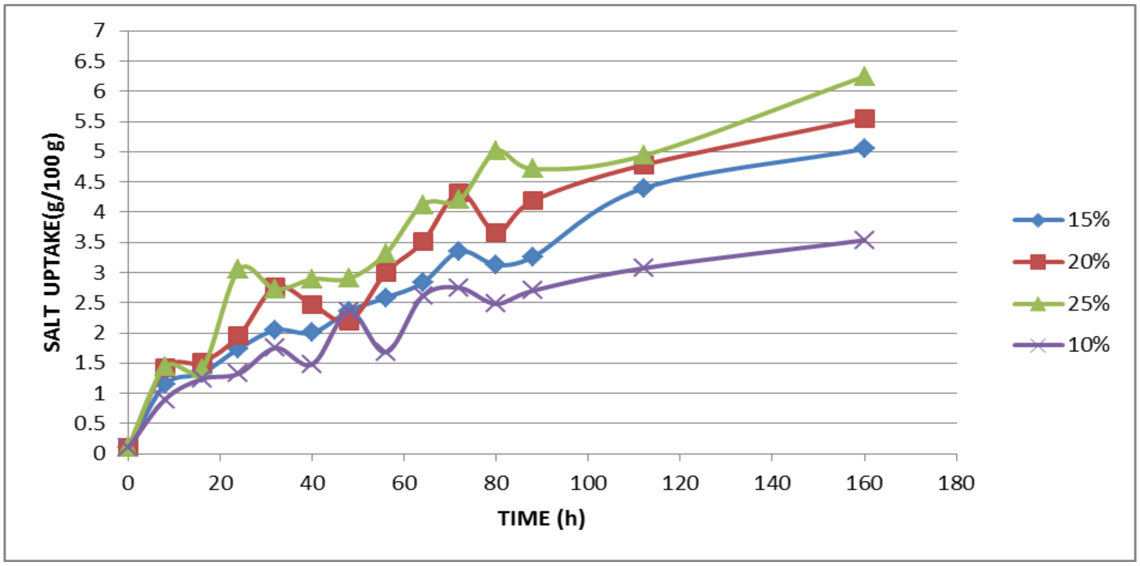

Fig. 2. Experimental herring salt uptake at different brining concentration (10, 15, 20, or 25%) during 160hrs of brining period

Trending of the data in Fig. (2) gives indication about how near each concentration's trail is to the others. It was noticed that salt uptake of the 10% experiment gives the farthest point against other experiments' endpoint data and that's because of the weakness of solution strength under low temperature and brining of whole fish with skin.

Table 1. Analysis of variance of the raw data and data replicates with significance level > 0.05

	Observed data averages			variance			***P*-value**
REPLICATES	**A**	**B**	**Mean**	**A**	**B**	**mean**	
10%	2.09	1.90	1.998	0.76	0.71	0.64	0.83
15%	2.53	2.51	2.52	1.67	1.06	1.3	0.999
20%	2.78	2.94	2.96	2.21	2.15	1.9	0.94
25%	3.5	3.22	3.36	3.27	2.43	2.75	0.91

The mentioned data in Table. (1) gives an indication about the raw data with their variances levels playing critical role in the trending accuracy. Remarkably, data variances has a non-significant effect (*P*> 0.05) on data values, which does not impact the modelling results and accuracy. Brine concentration, immersion time and velocity of agitation has a large impact on the salt uptake rate more than the fat content and size of fish **(Aitken & Baines, 1969)**. **Birkeland *et al.* (2005)** observed that, increasing brine concentrations, low degrees of temperature and existence of skin significantly reduced the weight gain of herring fillets during brining. It is worth mentioning that, herring fillets absorb salt faster than the knobbed or gutted herrings **(Gudmundsdottir & Stefansson, 1997)**.

The salt behavior shows the similar pattern for the different salting conditions despite the different steady-state concentrations attained for each of them. The scatter in the experimental salt concentration values may be due to the general biological variation between individual herrings **(Rodger *et al.*, 1984; Nielsen *et al.*, 2005)**.

Describing the behavior of salt transfer in Pelag model requires the evolvement of diffusion parameters (k1 and k2) as mentioned previously by MPC, which are presented in Table (2) for different brine concentrations.

Table 2. Predictive Peleg model parameters for herring salt uptake and its statistical fitting

Salt uptake						
Peleg model						
Estimated parameter for Peleg model			**Statistical parameters**			**P.E.V.**
Brine con.	**K1(h(g/100g)$^{-1}$**	**K2 (g/100g)$^{-1}$**	**R^2**	**SSE**	**RMSE**	
10%	14.21069	0.212660574	0.93	0.85	0.25	5.70
15%	14.70289	0.11740342	.96	0.89	0.25	9.52
20%	11.00787	0.118972	0.93	1.85	0.36	9.41
25%	8.800355	0.115634	0.94	2.03	0.38	9.65

Peleg rate constant (K_1) declined from 14.21069 for 10% brine solution to 8.800355 h(g/100g)$^{-1}$ for 25% concentration. Since the inverted K_1 (peleg rate constant) (eq. 2) is related to mass transfer rate, salt uptake increased with brine strength increment.

A similar attitude for salt uptake was proven in the study of **Checmarev *et al.* (2013)** on mackerel and the work of **Turhan *et al.* (2002)** on chickpea.

On the other hand, peleg capacity constant k_2 did not show sharp or clear pattern in terms of salt uptake. **Corzo and Bracho (2006)** found that there is unclear pattern of k_2 with respect to salt gain at sardine fillets during osmotic dehydration. Moreover, **Checmarev *et al.* (2013)** found that there is no clear pattern for k_2 related to process temperature at salt gain, glycerol gains and water loss. The predicted and experimental data for each concentration of brining solution (10, 15, 20, and 25%) were shown during 160hrs of brining periods in Figs. (2, 3, 4, 5, 6).

A paired sample t-test was performed to compare the 13 data point of salt uptake during 160 salting hours in every brine concentration (25, 20, 15 &10%) between observed data and predicted data in each concentration, and all of them are illustrated in Table (3).

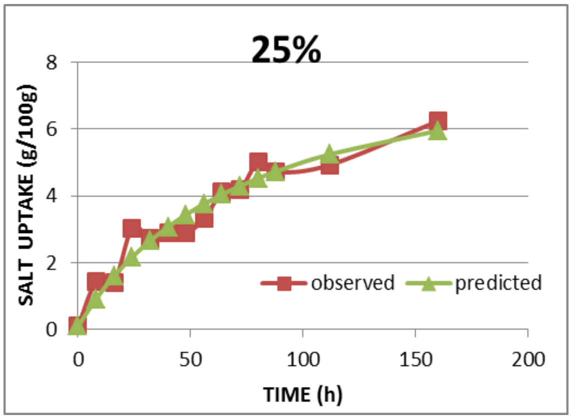

Fig. 3. Observed and predicted salt uptake at 25% brine concentration during 160 hrs of salting time

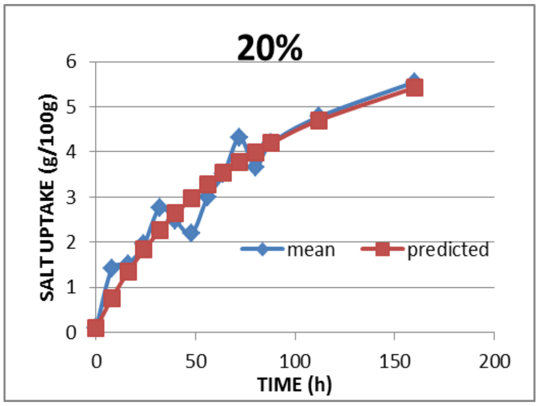

Fig. 4. Observed and predicted salt uptake at 20% brine concentration during 160 hr.

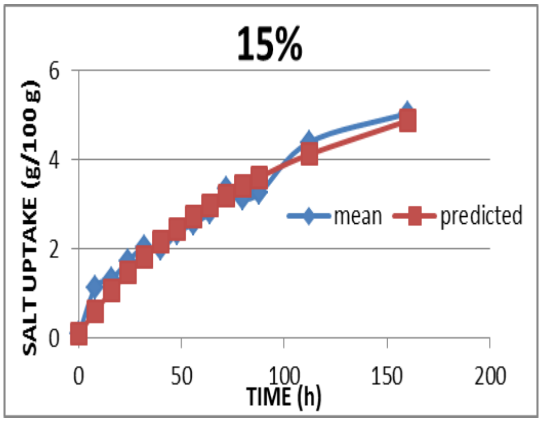

Fig. 5. Observed and predicted salt uptake at 15% brine concentration during 160 hrs of salting time.

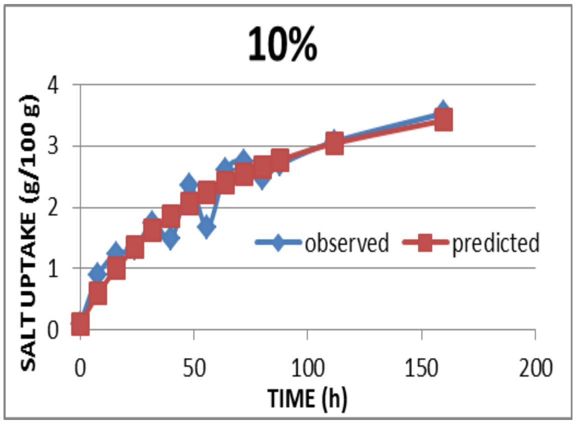

Fig.6. Observed and predicted salt uptake at 10% brine concentration during 160 hrs.

Table 3. Paired sample t-test between salt uptakes before and after MPC at *P*> 0.05

Concentration	**Mean**		**Standard deviation**		**t- value**	***P*- value**	**significance**
	Before	After	Before	After			
25%	3.36	3.33	1.66	1.68	0.318	0.756	Non-significant
20%	2.96	2.92	1.49	1.53	0.427	0.676	Non-significant
15%	2.53	2.48	1.30	1.36	0.689	0.503	Non-significant
10%	1.9974	1.977 4	0 .94	0.95	0 .296	.772	Non-significant

The determination coefficient (R^2) fluctuated from 0.93 to 0.96 for salt uptake predicted values at the four experimental concentrations. RMSE values were <0.4 in all cases. According to the statistical parameters, all have well goodness of fit (RMSE and R^2).

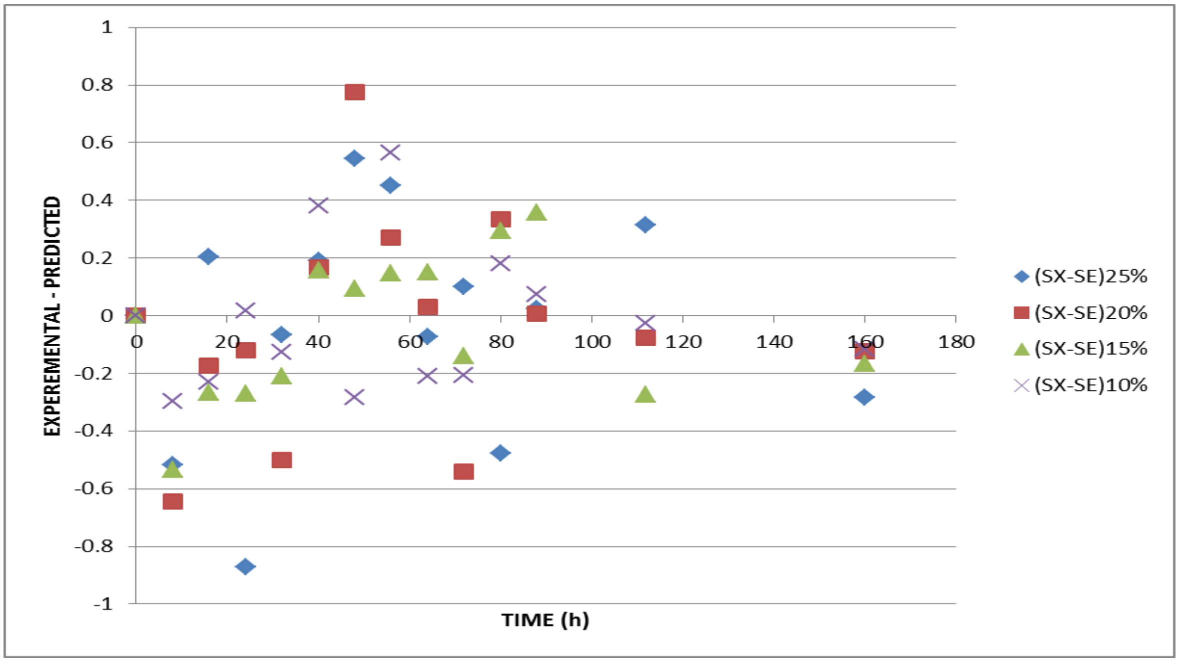

Fig. 7. Salting uptake residuals fitting between experimental and Peleg predicted values at various concentrations (10, 15, 20 & 25%) during salting time

The Peleg (MPC) model satisfactorily described the kinetics of salt uptake values at different time and different concentrations. The fitting of Peleg model (MPC) values with experimental values for salt uptake is shown in Fig. (7). It's observed that, for most analyzed conditions, the difference between the observed values and the Peleg (MPC) predicted values were small, which were verified by the statistical parameter (R^2 and RMSE) (Table 2). The equilibrium values that were predicted by Eq. (3) are shown in Table (1). The equilibrium salt results revealed to be overestimated by Peleg model

(MPC) capacity constant at Eq. (2), compared to the experimental equilibrium values. The projected residual analysis in Fig. (7) indicates that, for most of the studied times, smaller differences between predicted and experimental data were observed for the Pelag model. This can also be proved through the statistical R^2 and RMSE given in Table (1). Furthermore, no notable tendencies were observed for the residuals. The considered model was satisfactorily able to represent the kinetics of the salt gain by the samples (small residues, Fig. (7)) and revealed high correlation coefficients (R^2 between 0.93, 0.96, 0.93 and 0.94) and showed low RMSE (between 0.24, 0.25, 0.36 and 0.38).

Innovative predictive model (IPM) for salt uptake under different brine concentrations and times

In this section, the study finds a way in which the Peleg model (MPC) was considered valid for anticipating salt uptake at every brine concentration and during any salting time. Salt uptake prediction at any time is mainly based on the relationship between time and salt uptake according to Peleg model; however, for extended prediction for other non-tested concentrations, this relation was between salt uptake, brine concentration and time.

For non-further model implications, a good relationship was found between rate constant (k_1) and different brine concentrations. On the other hand, a good relationship was established between capacity constant (k_2) and different brine concentrations. Both relations were determined through polynomial model **(IPM)** via the following formula:

$AC_1\ (K1) = \alpha_1 C_s^{2} + \beta_1 C_s + \Omega_1$ ….................................. (Equ. 8)

$AC_2\ (K_2) = \alpha_2 C_s^{2} + \beta_2 C_s + \Omega_2$ …....................................… (Equ. 9)

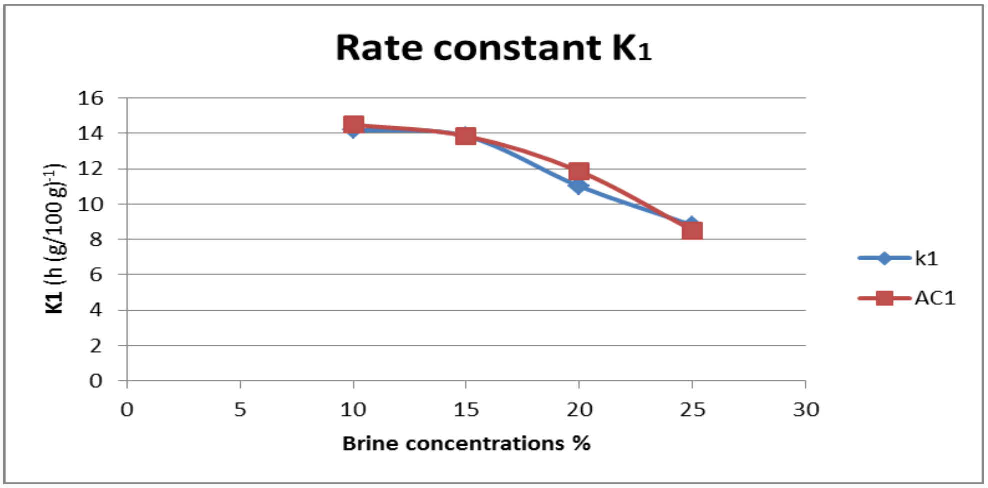

Fig. 8. Fitting the advanced constant AC_1 to peleg rate constant (MPC) values (K_1) of salt uptake during herring brining at concentrations (10, 15, 20 & 25%) .

Peleg rate constant (MPC) (k_1) showed a powerful trending behavior against different brine concentrations (**Fig. 8**) enabling for further analysis of this trend and fitting it by predictive polynomial model. Fitting with straight line linear regression did not give better fit to the Peleg constant (MPC) (k_1) data. It gave further higher variations at the final results in salt uptakes, except for those at 20% brine concentration, which had R^2 equivalent to 93% . However, it gave a little overestimation although results emerging by polynomial model **(IPM)** had an under estimation trend, with R^2 of 91%. Nevertheless, when applying models in industry process it's better to get underestimated results than overestimated because underestimation in this case is tiny and fixed with longer immersion time which will not cost the factory.

Peleg rate constant data (k_1) originated by polynomial model, which is called in this study the advanced constant 1 (AC_1) decreased after fitting the process to 13.851 instead of 14.70289. It didn't affect the accuracy of prediction in salt uptake. **Laub-Ekgreen *et al.* (2019)** found that, the salt uptake coefficient for the 16 % brine experiment was lower; that seemed somehow unanticipated.

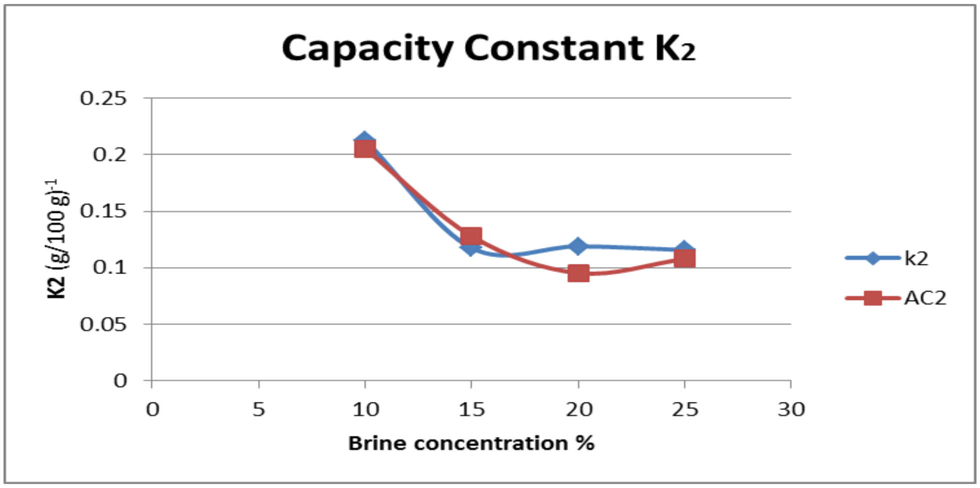

Fig. 9. Fitting the advanced constant AC_2 to peleg capacity constant (MPC) values (K_2) of salt uptake during herring brining at concentrations (10, 15, 20 & 25%) .

It was thought that capacity constant k_2 originated by polynomial model, which is called in this study the advanced constant 2 (AC_2) didn't show sharp or clear pattern according to salt uptake. Peleg capacity constant (MPC) was shown a minute trending behavior against different brine concentration (Fig. 9), which enabled for further analysis of this trend and fitting it by **(IPM)** predictive polynomial model.

Table 4. Coefficients of the polynomial model (IPM) and the fitting parameter

Coefficient PREDICTION									
Polynomial Model									
Estimated (IPM) coefficients for AC				**Statistical parameters for fitting estimated constants K1**			**Statistical parameters for fitting estimated constants K2**		
(IPM) CONSTANT	**AC_1 Estimated coefficients values**	**(IPM) CONSTANT**	**AC_2 Estimated coefficients values**	**R^2**	**SSE**	**RMSE**	**R^2**	**SSE**	**RMSE**
α_1	-0.027	α_2	0.0009	0.96	0.88	0.47	0.89	0.0008	0.014
β_1	0.5464	β_2	- 0.038						
Ω_1	11.73	Ω_2	0.4953						

The polynomial model (IPM) constants (α, β, Ω) are projected in Table (4). The polynomial model performed better in terms of AC_1, AC_2 constants, with the best fit being R2 of 0.96 and 0.89 and the lowest RMSE of 0.47 and 0.014, respectively. This improved the peleg model (MPC)'s ability to rely on the model for different constants for concentrations between those mentioned in the study with high accuracy.

Table 5. Data following the polynomial and peleg model analysis of variance between means

	R2		**SSE**		**RMSE**	
	WITHOUT$^{(G)}$	**WITH$^{(M)}$**	**WITHOUT$^{(G)}$**	**WITH$^{(M)}$**	**WITHOUT$^{(G)}$**	**WITH$^{(M)}$**
10%	0.927307	0.926621	0.840731	0.848666	0.245056	0.246209
15%	0.960181	0.964524	1.024856	0.913066	0.270562	0.25538
20%	0.9558	0.941048	1.840646	2.45498	0.362594	0.418755
25%	0.967094	0.958703	2.03278	2.55114	0.381049	0.426877

(M) Describes information created by utilizing the polynomial and peleg model.

(G) Describes data generated solely using the peleg model.

Although there is a difference between salt uptakes before and after using values of AC1 and AC_2, all these differences were not significant, as shown in Table (5). A paired sample t-test was performed to compare. The 13 data point of salt uptake during 160 salting hours in brine concentrations (10, 15, 20 & 25%) were determined between observed data (O) and data after predicted by both polynomial and peleg model (M). There were non-significant differences in salt uptake during 160 hrs of salting time between (O) and (M) after manipulation with mathematical calculations, which demonstrated better peak flow scores with non-significant change, compared to data before manipulation, as shown in Table (6). Except for concentrations of 20 % and 25%, there was a significant difference. But, according to R^2 value presented in Table (4), this significance didn’t change the accuracy of the prediction so much.

Table 6. A paired sample t-test that contrasted the data after polynomial and peleg model predictions (O) and the data after observations (M) ($P > 0.05$)

	Mean		**SD**		**df**	**T- value**	***P*- value**
	(O)	**(M)**	**(O)**	**(M)**			
10%	1.9974	1.9908	0.94322	0.96999	13	0.097	0.925
15%	2.5229	2.4873	1.29708	1.33401	13	0.507	0.621
20%	2.9580	3.0836	1.48647	1.68439	13	-0.707	0.492
25%	3.3607	3.4984	1.65841	1.78173	13	-1.179	0.260

The projected residual analysis in Fig. (10) shows a random scatter which indicates that residuals didn't contradict with the linear assumption and agreed with R^2 and RMSE (Table 5). This proves that new values given by the new model have high accuracy.While, Fig. (11) shows that the model has good fit for relatively small x values but it was not a good predictor of larger x values above 80 hrs as proved in Table (4) although maximum deviation didn't act as a serious problem at industrial processing results as it was negative residuals, which means that model gave underestimated results at those stages.

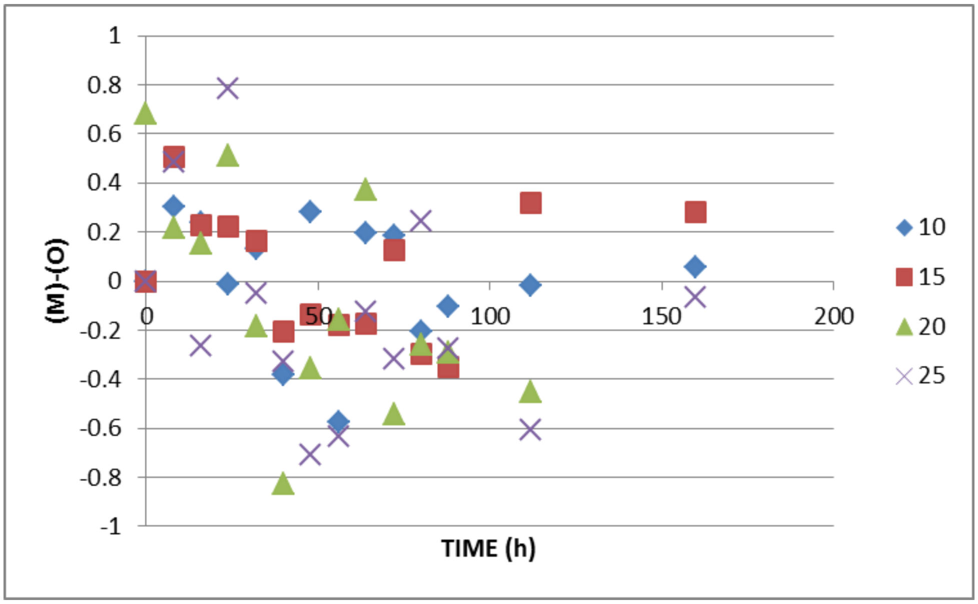

Fig. 10. Residual between observed data (O) and data after predicted by both polynomial and Peleg model (M)

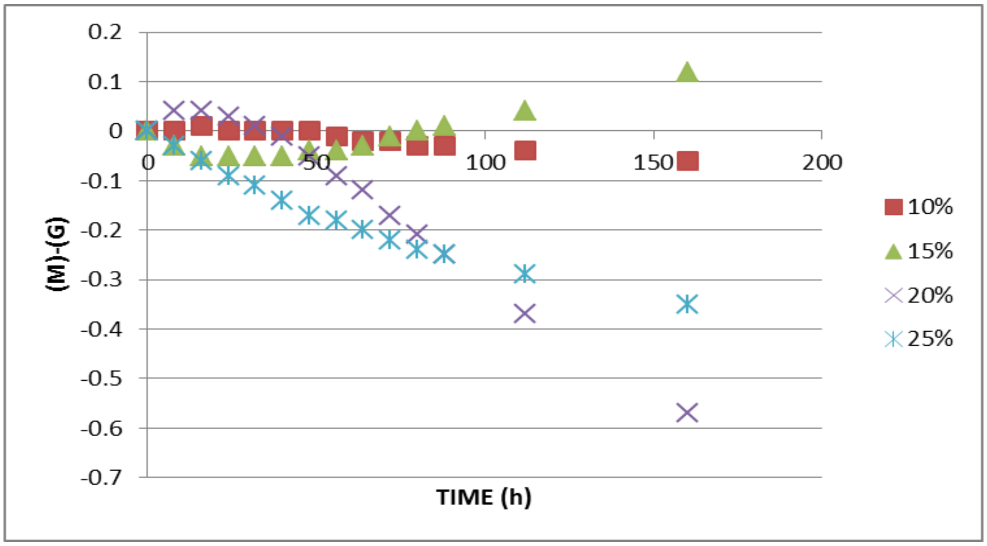

Fig. 11. Residual between data originated via using only Peleg model (G) and data after predicted by both polynomial and Peleg model (M)

CONCLUSION

The Peleg model can successfully predict salt intake during brining of herring within 160h of salting process at various ranges of salt concentrations (25%, 20%, 15%, or 10%) and fat content (7: 10%) at temperature 0° ±2 °C, with fat content ranging from 7- 10g/ 100g of flesh. Some logarithmic modifications were important for increasing Peleg capacity constant estimation in addition to nonlinear solving methods. Using polynomial models enabled advancing Peleg model ability in predicting salt intake at different concentrations that were not tested at the study. The model describes relatively experimental area which makes it more related to industrial operating conditions. It was the first study that modelling salt uptake under different brine concentrations. This was followed by a model with the ability to do that for other untested concentrations.

This model would be suitable for industrial-scale predicting of salt uptake for fish during brine salting. For illustration, a salt uptake could be targeted, and the fish would be removed from the brine once this level is achieved as previously predicted. This gives an ideal processing condition under various amounts. On the other hand, it makes the factory able to control velocity of processing condition and final quality parameter of the fish with such rigidity of tissue, water holding capacity, moisture content, salt content, and other physico- chemical parameters.

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