

An Engineering Approach to Design Perforated and Non Perforated Modified Atmospheric Packaging unit for Capsicum

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Abstract

An engineering approach was used to design a packet containing capsicum under perforated and non perforated packaging conditions. A model combining the Michaelis-Menten kinetics to describe the respiration rate of the product with mass transfer equation to describe the gas transfer across the package provided a good fit to the experimental data. Developed model can be successfully utilized under similar conditions.

Keywords: Perforated; Non perforated; Modified Atmosphere; Packaging; Capsicum

Introduction

The demand of capsicum is high in the market throughout the year whether in household or in hotel industry, internationally, its demand is high in European market. The high demand is due to its varied uses in fresh as well as in cooked form. It has been reported that 70% of the capsicum produced when reaches market exhibits variety of disorder, mainly due to poor post harvest handling, transport, storage, and marketing practices. Water loss, tissue softening, shriveling, and chilling injury (CI) are the major challenges, which limit the quality and post harvest life of capsicum [1-2].

There are numerous techniques available to reduce the post harvest losses namely controlled atmospheric storage (CAS), modified atmospheric packaging (MAP), refrigeration etc. Out of these technologies available, most widely used technique is MAP, as it provides advantage of low cost and easy implementation at the commercial level. MAP is atmospheric modification due to interplay of respiration process and exchange of gas through the packaging unit. Therefore, MAP is a dynamic system and gets influenced by many factors. Engineering design of MAP system starts from determination of respiration rate, optimal modified atmosphere for commodities combined with the required product filling weight/package area, the recommended gas permeability of the packaging film for O₂ and CO₂ [3-5]. Engineering approach obviates the need of trial and error approach to get desired in package gaseous concentration. Conducting trial is time consuming and also costly affair. Hence, engineering approach is an alternative that would be more appropriate way to save both cost and time.

Many scientists have reported positive effect of MAP on capsicum. For example, water loss may be significantly reduced by packaging capsicum in plastic films [6-7]. Gonzalez and Tiznado [7] reported 60% loss of firmness of capsicum within 20 days out of 40 days storage of produce at the temperature of 10°C, packed in LDPE, whereas significant loss of firmness was noticed in control within 10 days of storage. Additionally, wrapping green capsicums in plastic films contributed to better green-color retention compared to non-wrapped fruit [7-8]. Hence, MAP led to overall high quality produce with increased shelf life.

In the present study, an engineering approach was used to properly design a consumer packet containing capsicum under non perforated and perforated condition of MAP. Developed models were validated under different packaging conditions.

Mathematical consideration

Target in-package air composition for MAP: Recommended in-package optimal O₂ concentration should not be less than 2% and CO₂ concentration should range between 2-5% for the safe storage, as recommended by Manolopoulou et al. [9].

Consumer packet, sufficient to store 500 gm of capsicum i.e. four in numbers was considered for optimization under different MAP conditions for present study.

Engineering approach in designing of MAP

Mathematical modeling of gaseous exchange in MAP: There are basically two phenomena at stake in case of perforated modified packaging: respiration and mass transfer through film perforation as shown in (Figure 1). The respiration process involves O₂ consumption and CO₂ evolution.

Gas exchange through a polymeric film follows Fick's law of diffusion and obeys Eq. (1) as

$$J_{fi} = \frac{A_f P_{fi}}{L_f} (C_i^{out} - C_i^{in}) \quad (1)$$

where, C_i^{out} and C_i^{in} are the volumetric fraction of gas i outside and inside the packet, A_f is the film area, L_f is the thickness of the film, P_{fi} is permeability of the film. The amount of O₂ consumed and CO₂ produced in a packet can be obtained as follows:

$$O_2 \text{ consumption inside the packet} = M R_{o_2}$$

$$CO_2 \text{ evolution inside the packet} = M R_{co_2}$$

where, R_{o_2} and R_{co_2} are the respiration rate of O₂ consumption and CO₂ production and M is the mass of the produce.

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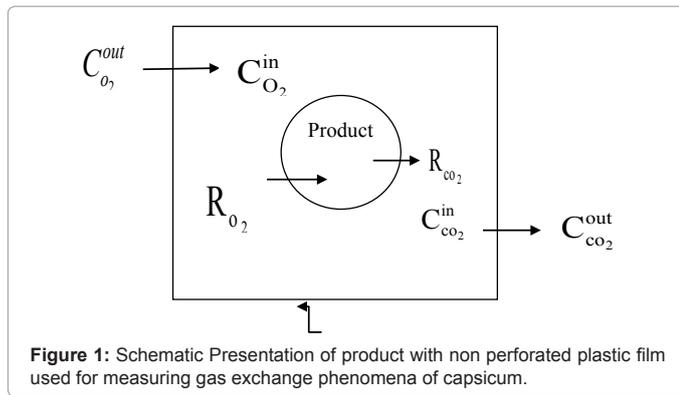


Figure 1: Schematic Presentation of product with non perforated plastic film used for measuring gas exchange phenomena of capsicum.

Applying mass balance across the film, the rate of change of O_2 and CO_2 inside the packet can be presented through Eqs. (2) and (3) respectively as

$$\frac{dC_{O_2}}{dt} = \frac{P_{O_2} A_f}{L_f V_f} (C_{O_2}^{out} - C_{O_2}^{in}) - \frac{R_{O_2} M}{V_f} \quad (2)$$

$$\frac{dC_{CO_2}}{dt} = \frac{P_{CO_2} A_f}{L_f V_f} (C_{CO_2}^{out} - C_{CO_2}^{in}) + \frac{R_{CO_2} M}{V_f} \quad (3)$$

where, C_{O_2} and C_{CO_2} are the volumetric fraction of O_2 and CO_2 gases inside the packet (v/v), t is the time, h, $C_{O_2}^{out}$ and $C_{CO_2}^{out}$ are the volumetric fraction of O_2 and CO_2 at the ambient condition, P_{O_2} and P_{CO_2} are the permeability of the film to the O_2 and CO_2 respectively, $ml\ m^{-2}\ h^{-1}\ atm^{-1}$, A_f is the surface area of the film, m^2 , L_f is the thickness of the film, m, R_{O_2} is the O_2 consumption rate of the product, $ml\ kg^{-1}\ h^{-1}$, R_{CO_2} is the CO_2 production rate of the product, $ml\ kg^{-1}\ h^{-1}$, and M is the mass of the product in the package, kg, V_f is the free volume in the packet, ml.

Mathematical modeling under perforated condition: Getting polymeric film having desired permeability for slow or high respiring produce in bulk is a difficult task. To overcome the problem encountered in continuous film, perforation is another way to increase the gas transmission rate (GTR). In case of perforated modified packaging, there are basically three phenomena at stake: respiration, mass transfer through film and mass transfer through perforation as shown in Figure.2. Porous material is responsible for gaseous exchange with its surroundings. Moreover, if the packaging material is perforated, it will represent an alternative route for gas transpiration in parallel to the packaging material. In this case, the total flow of the gas is given by Eq. (4) as

$$J_i = J_{fi} + J_{hi} \quad (4)$$

where, J_{fi} is the flow of a gas i across the film and J_{hi} is the flow of a gas i through the holes.

Applying mass balance for the O_2 and CO_2 gas exchange in a permeable package with perforation, the equations for the volumetric change of O_2 and CO_2 gases inside a perforated MAP with respiring produce are Eqs. (5) and (6) respectively Pandey and Goswami [10].

$$\frac{dC_{O_2}}{dt} = \frac{n_p U_{O_2}}{V_{fp}} (C_{O_2}^{out} - C_{O_2}^{in}) + \frac{P_{O_2} A_f}{L_f V_{fp}} (C_{O_2}^{out} - C_{O_2}^{in}) - \frac{R_{O_2} M}{V_{fp}} \quad (5)$$

$$\frac{dC_{CO_2}}{dt} = \frac{n_p U_{CO_2}}{V_{fp}} (C_{CO_2}^{out} - C_{CO_2}^{in}) + \frac{P_{CO_2} A_f}{L_f V_{fp}} (C_{CO_2}^{out} - C_{CO_2}^{in}) + \frac{R_{CO_2} M}{V_{fp}} \quad (6)$$

where, C_{O_2} and C_{CO_2} are the volumetric fraction of O_2 and CO_2 gases inside the container (v/v), t is the time, h, U_{O_2} and U_{CO_2} are the O_2 and CO_2 effective permeability through the perforation, $cm^3\ h^{-1}$, and $C_{O_2}^{out}$ and $C_{CO_2}^{out}$ are the volumetric fraction of O_2 and CO_2 at the ambient condition (v/v), $C_{O_2}^{in}$ and $C_{CO_2}^{in}$ are the permeability of the film to the O_2 and CO_2 respectively, $ml\ m^{-2}\ h^{-1}\ atm^{-1}$, $C_{O_2}^{out}$ is the O_2 consumption rate of the product, $ml\ kg^{-1}\ h^{-1}$, R_{CO_2} is the CO_2 production rate of the product, $ml\ kg^{-1}\ h^{-1}$, and M is the mass of the product in the package, kg, V_{fp} is the free volume in the packet, ml.

Materials and Methods

Respiration rate measurement

Detailed discussion about respiration is provided in the manuscript published by [10]. The coefficients used under Michaelis Menten (MM) type equations were also taken from the same manuscript.

Simulation of gas exchange dynamics

Non-linear differential Eqs. (2) and (3) were solved numerically using MATLAB software with initial concentrations of O_2 as 0.21(v/v) and CO_2 as 0.0003 (v/v). The parameters those influence in attaining steady state condition are mass of the product, area, permeability of the film, and surface area. Eqs. (2) and (3) are useful tool to predict the gaseous exchange over the time for optimization of gaseous conditions for packet design. Eqs. (2) and (3) are simultaneous equations, the solution of these equations would give variable oxygen concentration and carbon dioxide concentration inside the packet with time dt , h.

Measurement of gas exchange through packet

After exposing the product for four hours to the desired temperatures, capsicum weighing approximately 500 g (± 10 gm) i.e. four in numbers, were packed in the perforated and non perforated LDPE film (45 μ m). A sample of 1ml of headspace gas was drawn from each bag with a calibrated syringe through self-glued septum. Gas exchange was measured with GC. Three replications were performed for each set of experiments and the average is reported.

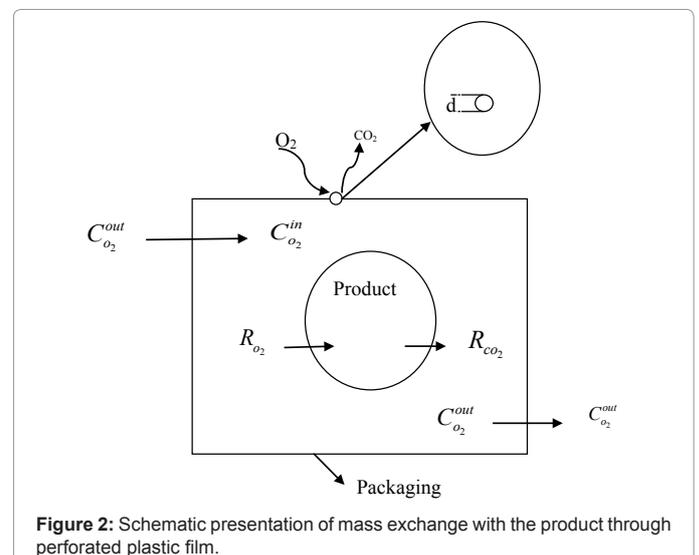


Figure 2: Schematic presentation of mass exchange with the product through perforated plastic film.

MAP designing under non perforated condition

At steady state, Eq. (2) is reduced to Eq. (7) as

$$AP(C_{out}^i - C_{in}^i) = RW \quad (7)$$

Optimum gaseous concentration was selected as 4% O₂ and CO₂ respectively. By substituting these concentrations in Model 2 [10] respiration rate for O₂ consumption was obtained as 4.25 and 8.45 ml (kg h)⁻¹ at the temperatures of 5 and 15°C, respectively. MM type equation was used to model the respiration process. With known mass of capsicum weighing 500 (±10) gm, i.e., with four in numbers was envisaged to be packed in a film having known GTR of 66.21 and 121.84 ml (m² h)⁻¹ at the temperatures of 5 and 15 °C respectively. The film used here was of LDPE (low density polyethylene), supplied by Reliance industry, Kolkata, of thickness 45 µm. GTR of the film was determined through a permeability tester (LABTHINK Model, Make, China). Substituting all the known parameters in Eq. (4), optimized area was obtained as 27×35 cm (with effective area of 0.1890 m²) and 27×36 cm (with effective area of 0.1944 m²) at temperatures of 5 and 15°C respectively.

MAP designing of packet parameter under perforated condition

For designing modified atmosphere packet under perforated condition, minimum area for packet size capable of holding 500 (±10) gm of capsicum i.e. four in numbers was determined as 23×23 cm as a consumer packet. Perforation diameter was selected as 0.3 mm based on the available facility and thin needle was used to obtain the desired diameter of perforation. With the known weight of the produce, with one perforation, permeability of the film and with the void volume of 608 ml (determined through water displacement method), gas exchange was recorded till the equilibrium point reached.

Validation of model

The mean relative percentage deviation modulus was evaluated as criteria for checking the fitting adequacy. The experimental and predicted values were then compared using Eq. (8) to determine the best fit equation Bhande et al. [11]. In general, lower the value of the module better is the agreement between experimental and predicted values.

$$E = \left[\frac{100}{N} \sum_{i=1}^n \frac{|R_{exp} - R_{pre}|}{R_{exp}} \right] \quad (8)$$

where, E is the mean relative deviation modulus in %; N is the number of respiration data points; R_{exp} is the experimental respiration rate in mlkg⁻¹h⁻¹ and R_{pre} is the predicted respiration rate in ml kg⁻¹ h⁻¹.

Results and Discussion

Validation of the developed model under non perforated condition

Steady state gaseous exchange under non perforated condition at temperatures of 5 and 15°C are shown in Figure. 3. In package steady state O₂ and CO₂ concentration were recorded as 3.28% O₂ and 3.12% CO₂ at temperature of 5°C, and 3.14% O₂ and 3.11% CO₂ at 15°C. At temperature of 5°C, the packet took around 16 days to reach the equilibrium state while at 15°C it attained the steady state after 8 days.

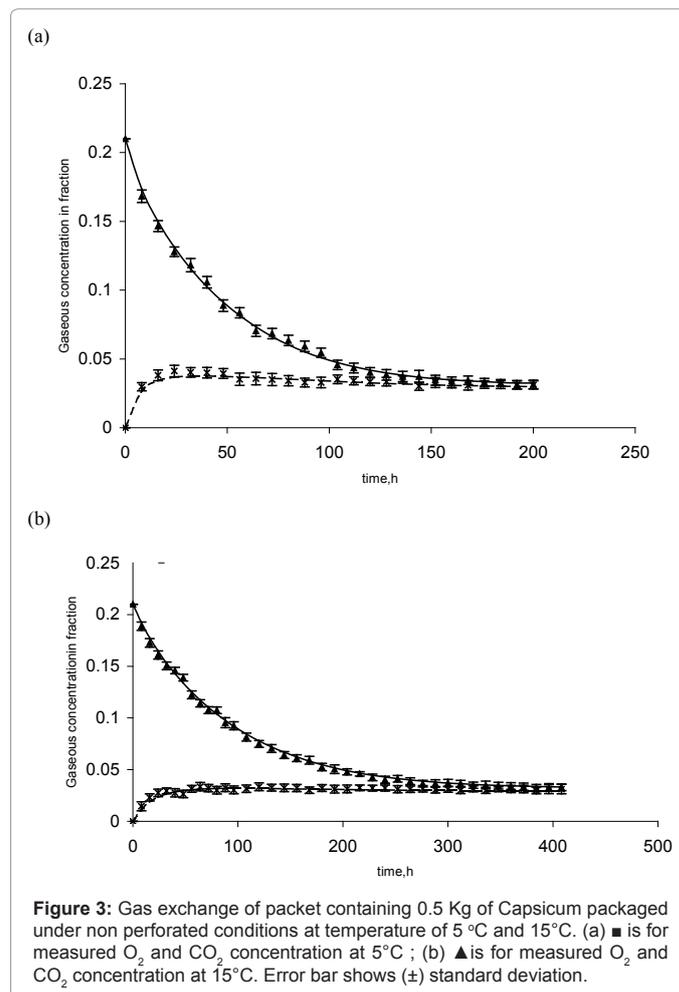
It took nearly 8-12 h more to attain the steady state than the predicted time.

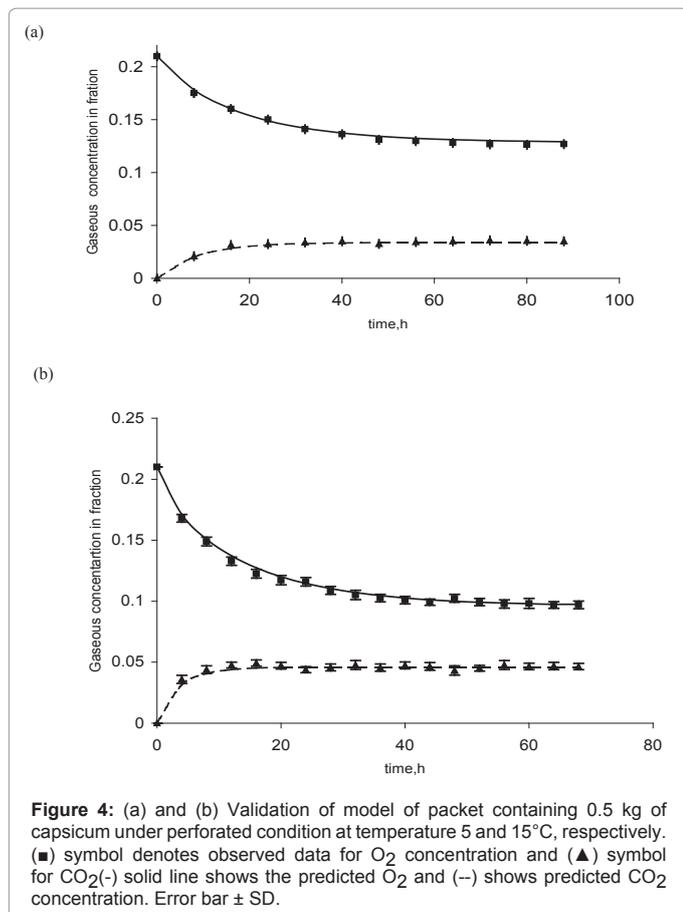
On validation of model (Eqs. 2 and 3), mean relative deviation moduli E (%) was recorded as 2.5% for O₂ and 5.29 % for CO₂ at temperature of 5°C. Similarly at 15°C, E (%) was recorded as 3.02% for O₂ and 3.64 % for CO₂. At both the temperatures, model provided good fit to the data obtained, as E value was less than 10 % [11].

Validation of developed model under perforated condition

Steady state in package O₂ and CO₂ concentrations were recorded as 12.56% and 3.78% at temperature of 5 °C and 9.98% and 4.24% at temperature of 15°C, respectively. Gas sampling was performed at specific time intervals and analyzed through gas chromatograph (GC). Models (Eqs. 5 and 6) were validated at temperature of 5 and 15°C as shown in Figure 4. Additionally, film took three to four days in establishing the steady state in package gaseous concentration. There was time gap of 4-8 h in between predicted and actual time to attain the steady state.

While validating, E values obtained for O₂ and CO₂ concentration were 1.68% and 7.53% at 5°C and 1.5% and 3.95% at 15°C respectively. Thus, the developed model fitted the data well and can be successfully utilized under such condition, as E values were less than 10%. Obtained gaseous concentration was well within the range prescribed by [9]. Furthermore, simulation was also done for area of 26×26 cm at temperature of 5°C, and the steady state O₂ and CO₂ concentration were obtained as 13.22% and 3% respectively, keeping the void volume constant. This showed that increasing area in case of perforated film





with constant mass and with constant diameter of hole resulted into higher O₂ concentration and lower concentration of CO₂. This is also evident from the Eqs. (5) and (6). Thus lower area was selected as it resulted into lower steady state concentration of O₂ and higher CO₂ concentration. Additionally, by varying the number of perforations, different gaseous in package steady state concentration could be obtained. Hence, size of packet was optimized for the dimension of 23×23 cm for the storage study at the different temperatures in case of perforated conditions.

As stated earlier, perforation provides an alternative way to equilibrate with outside condition for high respiration produce. Retention of high relative humidity inside the package, reduction of O₂ concentration and optimum rise of CO₂ i.e. above 2 % are the factors which contribute to the beneficial effects in MAP. Elevated CO₂ (greater than ~2 kPa) reduce the damaging effects of ethylene [12-13]. High in package relative humidity ensures the product hardness and less attack of microbes. Therefore, such system offers new opportunity for MAP of middle and high respiration produce in bulk and consumer packages in particular.

Conclusions

The Engineering approach is working, as the obtained equilibrium inside the packages is close to the predicted ones. Transient period was substantially less in case of perforated film compared to that for non perforated one. The effect of environmental temperature on headspace O₂ level can be predicted. Macro perforation with high headspace O₂

level, optimum CO₂ concentration and high RH offer new possibility for middle and high respiration produce in bulk and consumer packages.

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