Design of 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*—**Capsicum, Film, Modeling, Packaging.

I. 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 postharvest handling, transport, storage, and marketing practices (Juriach et al., 2000). Water loss, tissue softening, shriveling, and chilling injury (CI) are the major challenges, which limit the quality and postharvest life of capsicum (Lownds et al., 1994; Sethu et al., 1996; Smith et al., 2006).

There are numerous techniques available to reduce the postharvest 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 (Cameron et al., 1989; Exama et al., 1992; Lakakul et al., 1999). 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 (Fonsena et al., 2002). 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 (González and Tiznado, 1993; González -Aguilar et al., 1999). Gonzalez and Tiznado (1993) reported 60 % loss of firmness of capsicum within 20 days out of 40 days of storage duration of the produce at the temperature of 10 oC, packed in LDPE, whereas significant loss of firmness was noticed in control (unpacked and kept in room atmosphere) within 10 days of storage. Additionally, wrapping green capsicums with plastic films contributed to better green-color retention compared to non-wrapped fruit (González-Aguilar et al., 1999; Srinivasa et al., 2006). Hence, MAP led to overall high quality produce with increased shelf life.

In 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.

II. Theoritical Consideration

A. *Target in-package Air Composition for MAP*

Recommended in-package optimal O_2 concentration should not be less than 2 % and CO_2 concentration should range between 2-5 % for the safe storage, as recommended by Manolopoulou et al. (2010).

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.

B. *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 Fig.1. The respiration process involves O_2 consumption and CO_2 evolution.

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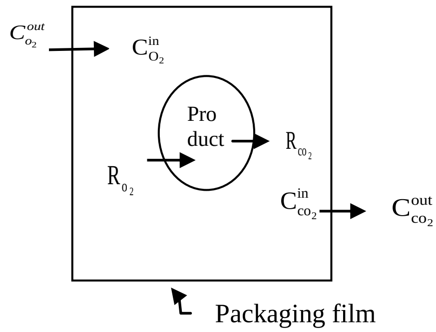


Fig.1 Schematic Presentation of product with non-perforated plastic film used for measuring gas exchange phenomena of capsicum.

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

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

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_f is permeability of the film.

The amount of O_2 consumed and CO_2 produced in a packet can be obtained as follows:

O_2 consumption inside the packet = M R_{O2}

CO_2 evolution inside the packet = M R_{CO2}

where, R_{O2} and R_{CO2} are the respiration rate of O_2 consumption and CO_2 production and M is the mass of produce.

Applying mass balance across the film, the rate of change of O_2 and CO_2 inside the packet is represented as Eq. 2 and Eq. 3:

$$\frac{dC_{0_2}}{dt} = \frac{P_{o_2} A_f}{L_f V_f}\left(C_{o_2}^{out} - C_{o_2}^{in}\right) - \frac{R_{o_2} M}{V_f} \qquad (2)$$

$$\frac{dC_{co_2}}{dt} = \frac{P_{co_2} A_f}{L_f V_f}\left(C_{co_2}^{out} - C_{co_2}^{in}\right) + \frac{R_{co_2} M}{V_f} \qquad (3)$$

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 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.

C. Mathematical modeling under perforated condition

Getting desired permeable film for slow respiring produce in bulk or for high respiring produce is a difficult task. To overcome the problem encountered in a continuous film, use of 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 Fig. 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. 5:

$$J_i = J_{fi} + J_{hi} \qquad (5)$$

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.

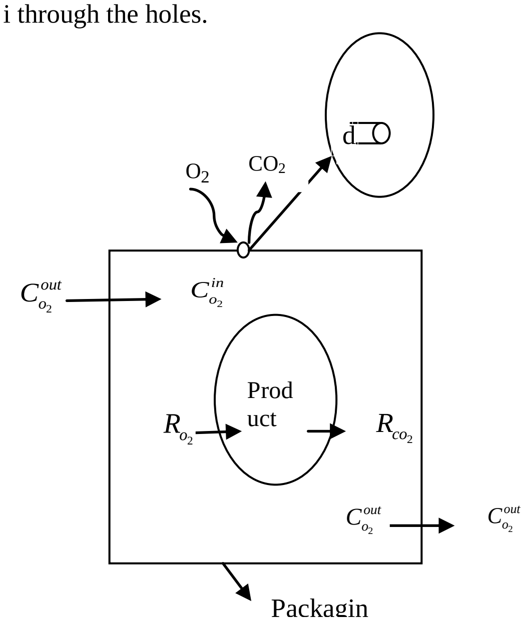


Fig. 2 Schematic presentation of mass exchange with product under perforated plastic film.

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 Eq. 6 and Eq. 7 (Pandey and Goswami (2012)):

$$\frac{dC_{0_2}}{dt} = \frac{n_p U_{o_2}}{V_{fp}}\left(C_{o_2}^{out} - C_{o_2}^{in}\right) + \frac{P_{o_2} A_f}{L_f V_{fp}}\left(C_{o_2}^{out} - C_{o_2}^{in}\right) - \frac{R_{o_2} M}{V_{fp}} \qquad (6)$$

$$\frac{dC_{co_2}}{dt}=\frac{n_p U_{co_2}}{V_{fp}}\left(C_{co_2}^{out}-C_{co_2}^{in}\right)+\frac{P_{co_2}A_f}{L_f V_{fp}}\left(C_{co_2}^{out}-C_{co_2}^{in}\right)+\frac{R_{co_2}M}{V_{fp}} \quad (7)$$

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}. $C_{o_2}^{out}$ and $C_{co_2}^{out}$ are the volumetric fraction of O_2 and CO_2 at the ambient condition (v/v), P_{o_2} and P_{co_2} are the permeability of the film to the O_2 and CO_2 respectively, ml m m^{-2} h^{-1} atm^{-1}, 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_{fp} is the free volume in the packet, ml.

III MATERIALS AND METHODS

A. Respiration rate measurement

Detailed discussion about respiration is provided in the manuscript published by Pandey and Goswami (2011). Coefficients obtained under MM type equation were also taken from the same manuscript.

B. Simulation of gas exchange dynamics

Non-linear differential Eq.2 and Eq.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). Here, mass of the product, area and permeability of the film, and surface area influence steady state condition. Eq. 2 and Eq. 3 are a useful tool to predict the gaseous exchange over the time for optimization of packet design. Eq. 2 and Eq. 3 are simultaneous equation, the solution of these equations would give variable oxygen concentration and carbon dioxide concentration inside the packet with time dt.

C. 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 number, were packed in the perforated and *non-perforated LDPE film (45 μm). 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 a Gas Chromatograph (GC). Three replications were performed for each set of experiments.*

D. MAP designing under non perforated condition

At the steady state, the Eq. 2 is reduced to the following form as Eq. 9:

$$AP(C_{out}^{i}-C_{in}^{i})=RW \quad (9)$$

Optimum gaseous concentration was selected as 4 % O_2 and CO_2 respectively. By substituting these concentrations in Model 2 (Pandey and Goswami (2011)), respiration rate for O_2 consumption was obtained as 4.25 and 8.45-ml (kg h)$^{-1}$ at the temperature 5 and 15 ^oC, respectively. MM type equation was used to model the respiration process. And constants for MM Eq. were taken from Pandey and Goswami (2011). With known mass of capsicum weighing 500 (±10) gm, i.e., with four in number was to be packed and with known gas transmission rate (GTR) of film (66.21 and 121.84 ml (m^2 h)$^{-1}$ at the temperature 5 and 15 ^oC 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 permeability tester (LABTHINK Model, Make, China). Substituting all the known parameters in Eq. (4), optimized area was obtained as 27x35 cm (with effective area of 0.1890 m^2) and 27x36 cm (with effective area of 0.1944 m^2) at temperatures of 5 and 15 ^oC respectively.

E. 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 number was determined as 23x23 cm. Perforation diameter was selected as 0.3 mm and thin needle was used to obtain the desired diameter of perforation. With the known weight of produce, with one perforation, permeability of film, and with the void volume of 608 ml (determined through water displacement method).

F. 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.,2008). In general, lower the value of moduli better is the agreement between experimental and predicted values.

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

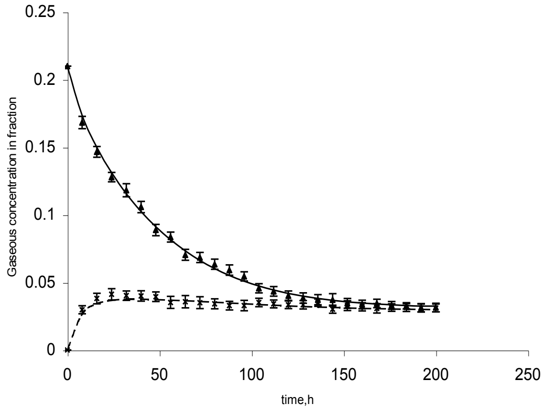
where, E is the mean relative deviation modulus in %; N is the number of respiration data points; R_{exp} is the experimental respiration rate in ml kg^{-1} h^{-1} and R_{pre} is the predicted respiration rate in ml kg^{-1} h^{-1}.

IV. RESULTS AND DISCUSSION

A. Validation of developed model under perforated condition:

Steady state gaseous exchange under non perforated condition at temperatures of 5 ^oC and 15 ^oC are shown in Fig.3. In package steady state O_2 and CO_2 concentration were recorded as 3.28 % O_2 and 3.12 % CO_2 at temperature of 5 ^oC, and 3.14 % O_2 and 3.11 % CO_2 at 15 ^oC. At temperature of 5 ^oC, the packet took around 16 days to reach the equilibrium state while at 15 ^oC it attained the steady state after 8 days. It took nearly 8 - 12 h more to attain the steady state than the predicted time.

(a)



(b)

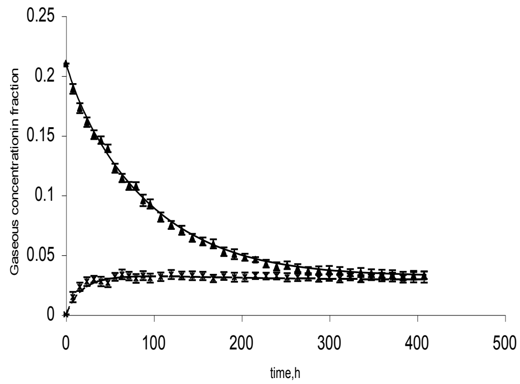


Fig. 3. Gas exchange of packet containing 0.5 Kg of Capsicum packaged under non perforated conditions at temperature of 5 ^oC and 15 ^oC. (a) ■ is for measured O_2 and CO_2 concentration at 5 ^oC ; (b) ▲is for measured O_2 and CO_2 concentration at 15 ^oC. Error bar shows (±) standard deviation.

On validation of model (Eqs. 3.17 and 3.18), mean relative deviation moduli 'E' (%) was recorded as 2.5 % for O_2 and 5.29 % for CO_2 at temperature of 5 ^oC. Similarly at 15 ^oC, 'E' (%) was recorded as 3.02 % for O_2 and 3.64 % for CO_2. At both temperatures, model provided good fit to the data obtained, as 'E' value was less than 10 %.

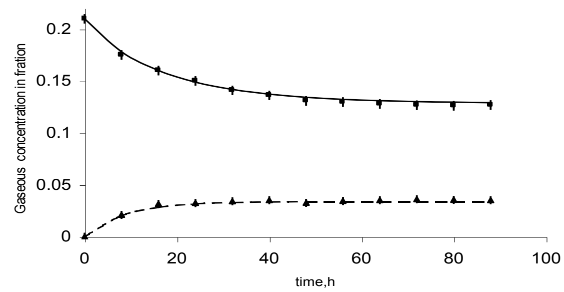
B. Validation of developed model under perforated condition: -

Steady state in package O_2 and CO_2 concentrations were recorded as 12.56 % and 3.78 % at temperature of 5 ^oC and 9.98 % and 4.24 % at temperature of 15 ^oC, respectively. Gas sampling was performed at a specific time intervals and analyzed through GC. Models (Eqs. 6 & 7) were validated at temperature of 5 and 15 ^oC as shown in Fig. 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.

On validation, obtained E values for O_2 and CO_2 concentration were 1.68 % and 7.53 % at 5 ^oC and 1.5 % and 3.95 % at 15 ^oC 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 Manolopoulou et al. (2010). Furthermore, simulation was also done for area of 26x26 cm at temperature of 5 ^oC, and the steady state O_2 and CO_2 concentration were obtained as 13.22 % and 3 % respectively, keeping 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 O_2 concentration and lower concentration of CO_2. This is also evident from the Eqs. (7) and (8). Thus lower area was selected as it resulted into lower steady state concentration of O_2 and higher CO_2 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 23x23 cm for the storage study at the different temperatures in case of perforated conditions.

As stated earlier, perforation provides an alternative way for high respiration produce. Retention of high relative humidity inside package, reduction of O_2 concentration and optimum rise of CO_2 i.e. above 2 % are the factors which contribute to the beneficial effects in MAP. Elevated CO_2 (greater than ~ 2 kPa) reduce the damaging effects of ethylene (Herner, 1987; Kader et al., 1989). 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.

(a)



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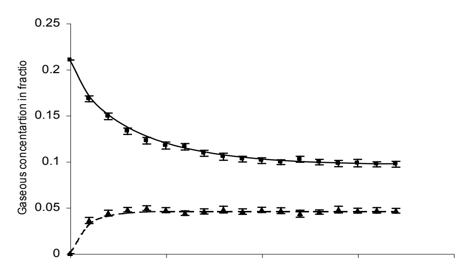

Fig. 4 (a) and (b) Validation of model of packet containing 0.5 kg of capsicum under perforated condition at temperature 5 and 15 ^OC, respectively. (■) symbol denotes observed data for O_2 concentration and (▲) symbol for CO_2. (-) solid line shows the predicted O_2 and (--) shows predicted CO_2 concentration. Error bar ± SD.

V. Conclusion

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 non-perforated one. The effect of environmental temperature on headspace O_2 level can be predicted. Macro perforation with high headspace O_2 level, optimum CO_2 concentration and high RH offer new possibility for middle and high respiration produce in bulk and consumer packages.

References

[1] Bhande,S.D., Ravindra,M.R. & Goswami,T.K.(2008).Respiration rate of banana fruit under aerobic conditions at different storage temperatures. Journal of food Engineering, 87(1),116-123. http://dx.doi.org/10.1016/j.jfoodeng.2007.11.019

[2] Cameron, A.C, Boylan-Pett, & Lee, W. J. (1989). Design of modified atmosphere packaging systems: modeling oxygen concentrations within sealed packages of tomato fruits. Journal of Food Science, 54(6), 1413–1415. http://dx.doi.org/10.1111/j.1365-2621.1989.tb05123.x

[3] Exama, A., Arul, J., Leneki, R.W., Lee, L.Z., & Toupin, C. (1993). Suitability of plastic films for modifies atmosphere packaging of fruits and vegetables. Journal of Food Science.58, 1365–1370. http://dx.doi.org/10.1111/j.1365-2621.1993.tb06184.x

[4] Fonseca S. C., Oliveira. F.A.R., & Brecht, J. K. (2002). Modeling of respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. Journal of Food Engineering, 52, 99–119. http://dx.doi.org/10.1016/S0260-8774(01)00106-6

[5] González-Aguilar, G.A., Cruz, R., Baez, R., and Wang, C.Y. (1999). Storage quality of bell peppers pretreated with hot water and polyethylene packaging, Journal of food quality.22, 287–299. http://dx.doi.org/10.1111/j.1745-4557.1999.tb00558.x

[6] González,G., and Tizado,M.(1993).Postharvest physiology of bell peppers stored in low density polyethylene bags.Lebensmittel Wissenschaft und Technologie,26,450–455. http://dx.doi.org/10.1006/fstl.1993.1089

[7] Hener, R.C. (1987). High CO2 effect on plant organs. In: J.Weichmann (Ed.). Post harvest Physiology of Vegetables. Marcel Dekker, New York, p.239.

[8] Jurin, V. and Karel, M.(1963).Studies on control of respiration of McIntosh apples by packaging methods, Food Technology, 176, 104.

[9] Kader, A.A., Zagory, D., & Kerbel, E.L. (1989). Modified atmosphere packaging of fruits and vegetables. Critical Reviews in Food Science Nutrition, 28, 1–30. http://dx.doi.org/10.1080/10408398909527490

[10] Lakakul, R., Beaudry, R.M., & Hernandez, R.J. (1999). Modeling respiration of apple slices in modified atmosphere packages. Journal of Food Science, 64(1), 105–110. http://dx.doi.org/10.1111/j.1365-2621.1999.tb09870.x

[11] Lownds, N.K., Banaras, M., & Bosland, P.W. (1994). Postharvest water loss and storage quality of nine pepper (Capsicum) cultivars. HortScience, 29, 191–193.

[12] Manolopoulou, H., Xanthopoulos, G., Douros, N., & Lambrinos, Gr. (2010). Modified atmospheric packaging storage of green peppers: Quality criteria. Biosystem Engineering. 106, 535–543. http://dx.doi.org/10.1016/j.biosystemseng.2010.06.003

[13] Pandey, S. K. & Goswami, T. K. (2011). Modeling of Respiration Rate of Capsicum at Various Temperatures. International Journal of Food Engineering: Vol. 7: Iss. 5, Article 4.DOI: 10.2202/1556- 3758.2047.

[14] Pandey, S. K. & Goswami, T. K. (2012). Modeling perforated - Mediated Modified Atmospheric Packaging of Capsicum. 12 JAN 2012, DOI: 10.1111/j.1365-2621.2011.02877.x, Int. Jour. of Food Science and Technology. http://dx.doi.org/10.1111/j.1365-2621.2011.02877.x

[15] Sethu, K.M.P., Prabha, T.N., & Tharanathan, R.N. (1996). Post-Harvest biochemical changes associated with the softening phenomenon in Capsicum annuum fruits. Phytochemistry 42, 961–966. http://dx.doi.org/10.1016/0031-9422(96)00057-X

[16] Smith, D.L., Stommel, J.R., Fung, R.W.M., & Whitaker, B.D. (2006).Influence of cultivar and harvest method on postharvest storage quality of pepper(Capsicum annuum L.) fruit. Postharvest Biology and Technology, 42, 243–247. http://dx.doi.org/10.1016/j.postharvbio.2006.06.013

[17] Srinivasa, P.C., Prasanth K.V.H., Susheelamma, N.S., Ravi, R., & Tharanathan, R.N. (2006). Storage studies of tomato and bell pepper using eco-friendly films. Journal of the Science and Food and Agriculture, 86, 1216–1224. http://dx.doi.org/10.1002/jsfa.2472