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Project Title **Adhesion of Seasoning Onto Fried Chips**

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Adhesion of Seasoning Onto Fried Chips

Abstract:

Tortilla chips were made by sheeting and baking masa dough (300°C for 100-110 s) followed by frying in soybean oil (190°C for 40 s). Wind tunnel experiments were conducted to characterize the adhesion of seasoning particles onto tortilla chips. Seasoning powder was supplied by Frito Lay. In wind tunnel experiments, a tortilla chip with a monolayer of known amount of seasoning was placed in a rectangular channel through which air at known flow rate was flown and the amount of seasoning retained by the chip at different flow rates was measured. These experiments were conducted for different inclinations of wind tunnel for different particle size ranges of seasoning, oil content of tortilla chip, viscosity and surface tension of oil. Based on boundary layer theory, the inferred adhesion force of seasoning particle and chip surface from the experimental data was in the range of 1.6 x 10^{-9} to 3.3 x 10^{-7} N. Results showed that adhesion strength increases with increasing seasoning particle size (32 - 300μm), oil content of tortilla chip (24-32%), viscosity of oil (μ=55.9-72.2 cP) and surface tension of oil (σ= 27.5 – 34.1mN/m). The calculated values of adhesion force accounting for van der Waals, electrostatic and capillary forces were in the range of 2.7×10^{-8} to 1.3×10^{-7} N and showed the same qualitative trend as the experimental data for chips with different seasoning particle sizes and surface tensions of oil.

Materials and Methods

Medium-fine granular masa flour with 9.5 to 11.5% moisture content was obtained from Minsa Corn (Red Oak, Iowa). Distilled water was mixed with masa flour using standard kitchen mixer in order to give a dough of 53% by weight moisture content. Then the finished masa dough was sheeted using a sheeting roller, of 0.06 in gap. Then the sheeted dough was cut into a final shape using a cutter, baked for 100-110 seconds at 300°C in an oven. The baked chips were then equilibrated at room temperature from 5-10min,in order to prevent formation of blisters or puffing upon frying. The moisture value of the baked chips was maintained at about 46-48% by weight. The baked tortilla chip was then fried for 40 seconds in a laboratory deep-fryer in soybean oil maintained at 190°C. During the frying process, a temperature probe was used to monitor the oil temperature. The excess surface oil was removed by contacting the fried chip with an absorbent paper for 22 hours. The fat content of the tortilla chip (24%) was then determined using Soxhlet extraction method (AOAC Method 920/39C for Cereal Fat). The surface was characterized in terms of blister distribution and was compared with commercial Doritos chips.

Experiment Procedure

The experiments were carried out with seasoning supplied by Frito Lay. The seasoning was fractionated to different particle sizes (32 to 300 microns) using sieving. The experimental system for wind tunnel experiments consisted of a rectangular channel with a wire mesh at the center of the channel. A single fried chip with known amount of seasoning in the form of a thin monolayer was prepared and was mounted onto the rectangular channel. An air blower was used to flow air through the channel at a constant flow rate. The flow rate of the air was measured using a flow meter. The weight of the fried chip with known amount of seasoning was measured before and after blowing air over the product for different times. The amount of seasoning retained after exposure to air was then calculated. The amount of seasoning retained reached a limiting value at 3 min at a fixed airflow rate. In all subsequent experiments, this procedure was repeated at different airflow rates (0.516, 0.671, 0.844, 1.034, 1.115 m/s) for exposure time of 3 min. In order to ascertain the effect of gravity on seasoning removal, the wind tunnel was mounted at different inclinations, i.e. 0^o, 30^o, 45^o and 60^o. These windtunnel experiments were then repeated for different angles, particle size ranges, oil contents of tortilla chip, viscosities and surface tensions of oil.

Analysis of Data

An idealized schematic of air flow over an inclined chip with a monolayer of seasoning particles is shown in Fig. 1. A boundary layer will develop in the vicinity of the chip surface with the boundary layer thickness $\delta(x)$ increasing with the distance x from the leading edge (see Fig 2). Consequently, there is a critical distance x_{crit} at which the drag force counterbalances the frictional forces. This implies that the drag force acting on the seasoning particles at distances less than x_{crit}, the drag force, being higher than the frictional forces, can lift the seasoning particle from the chip surface. Therefore the region from the leading edge where $x < x_{crit}$ will be bare since all the seasoning particles will be removed (see Fig. 2b).

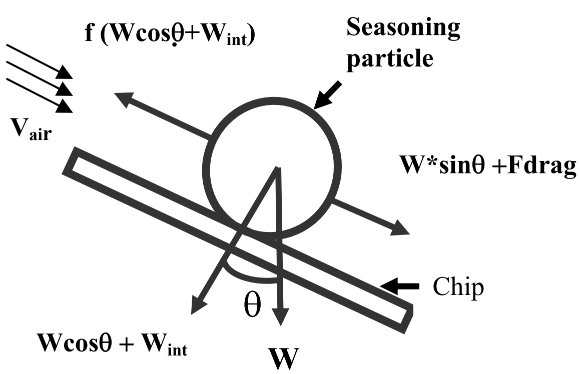


Figure1: Schematic of the windtunnel experiment.

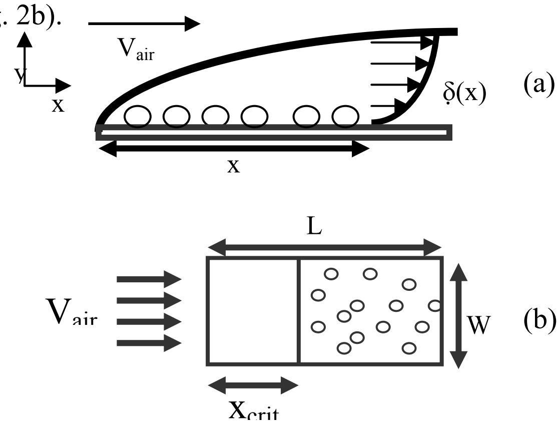


Figure 2 Side view (a) of top view (b) of air flow over the chip.

One can evaluate x_{crit} from the condition of mechanical equilibrium of a seasoning particle at that location as given by,

$$\tau(x_{crit}) + W \sin\theta = f(W \cos\theta + W_{int}) \quad (1)$$

where f is the friction coefficient, W is the weight of the seasoning particle and W_{int} is the attractive interaction force between the seasoning particle and the chip surface.

The predicted model, $x^*_{crit,model}$ evaluation became,

$$x^*_{crit,model} = \frac{F^*_{drag}\, a \,\mathrm{Re}^{1/2}}{L^*\left(f \cos\theta + f W^*_{\mathrm{int}} - \sin\theta\right)} \quad (2)$$

Based on the assumption that the leading edge of the chip of distance x_{crit} is bare, the weight of seasoning particle retained on the chip can be related to x_{crit} via,

$$1 - \frac{S}{S_0} = x^*_{crit,\exp} \quad (3)$$

where the fraction of seasoning loss S is the weight of seasoning retained on the chip after exposure to air flow and S_0 is the total weight of the seasoning that is loaded onto the chip before exposure to air flow. Therefore $x^*_{crit,\exp}$ is the fraction of seasoning that is removed by airflow based from experimental data.

Equation 3 was fitted to Equation 2 to infer the two unknown parameters, the friction coefficient (f) and adhesion force (W^*_{int}). JMP software was used to solve both f and W^*_{int} by minimizing the error between experimental data and the predicted model as given by,

$$\varepsilon = \sum \left[x^*_{crit,\exp} - x^*_{crit,\mathrm{mod}\,el} \right]^2 \quad (13)$$

The estimated values f and W^*_{int} were then used to evaluate predicted $x^*_{crit,\mathrm{mod}\,el}$. By obtaining the particle adhesion model fraction of seasoning removed, $x^*_{crit,\mathrm{mod}\,el}$, a comparison with the fraction of seasoning removed from wind tunnel experimental data ($x^*_{crit,\exp}$) was generated.

The experimental force of adhesion was verified using theoretical values of force of adhesion, including: van der Walls, capillary and electrostatic image force. And the inferred force of adhesion between theoretical and simulation model results were compared.

Results and Discussion

From the comparison of blister size distribution as well as the visual appearance of the chip manufactured by the laboratory process with the commercial Dorito product, the laboratory process was optimized. In the optimized process, tortilla chips were made by sheeting and baking masa dough (300°C for 100-110 s) followed by frying in soybean oil (190°C for 40 s). In wind tunnel experiments, the amount of seasoning loss increased with air velocity (see Figure 3). The adhesion force was found to be the smallest for fine particles (32-64μm) and decreased progressively for medium (64-125μm), large (125-180μm) and coarse (180-300μm) particle sizes. The particle size distribution of seasoning (not shown here) indicated that the predominant weight fraction of the seasoning powder was in the particle size range of 125-180μm. As expected, the seasoning loss was higher at higher inclination because of increased component of gravity acting along the chip surface (not shown here). Wind tunnel experimental results also showed that the force of adhesion increased with increasing oil content of tortilla chip (24-32%) (see Figure 4), viscosity of oil (μ=55.9-72.2 cP) (see Figure 5) and surface tension of oil (s= 27.5 - 34.1mN/m) (see Figure 6).

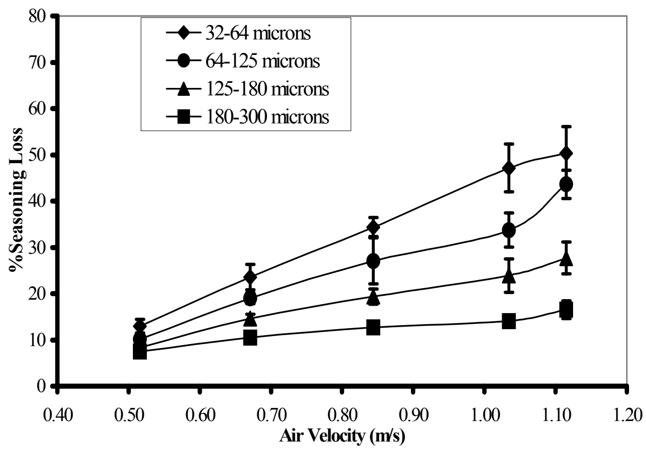


Fig 3: Effect of particle size for 24% chip at 0^0.

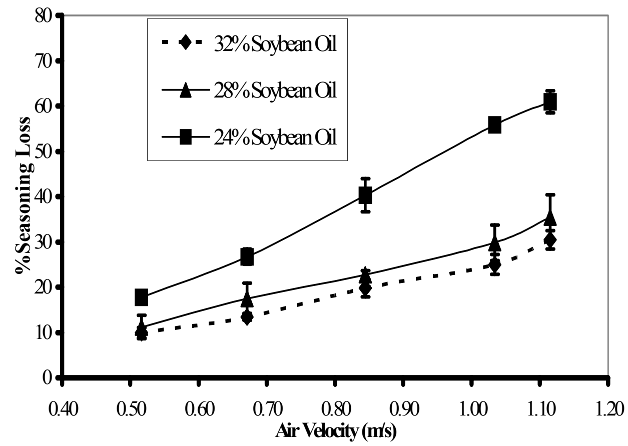


Fig 4:Effect of oil content at 60^o - part size 125-180 μm.

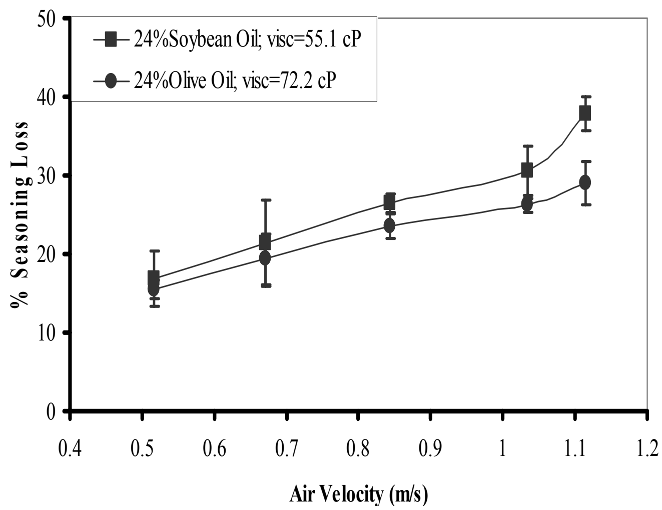


Figure 5: Effect of viscosity oil at 60^0-particle size 125-180μm

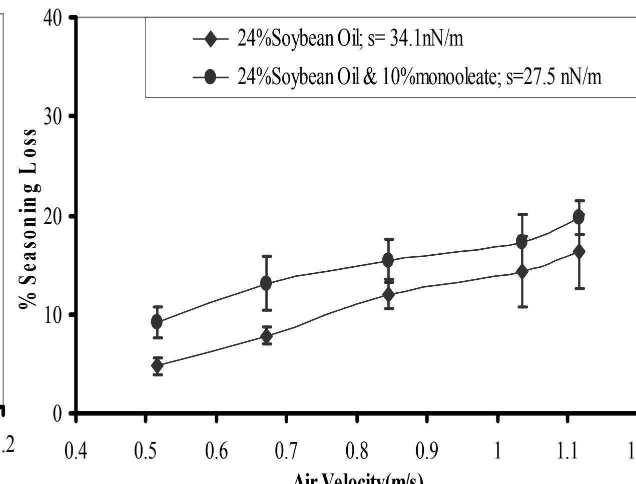
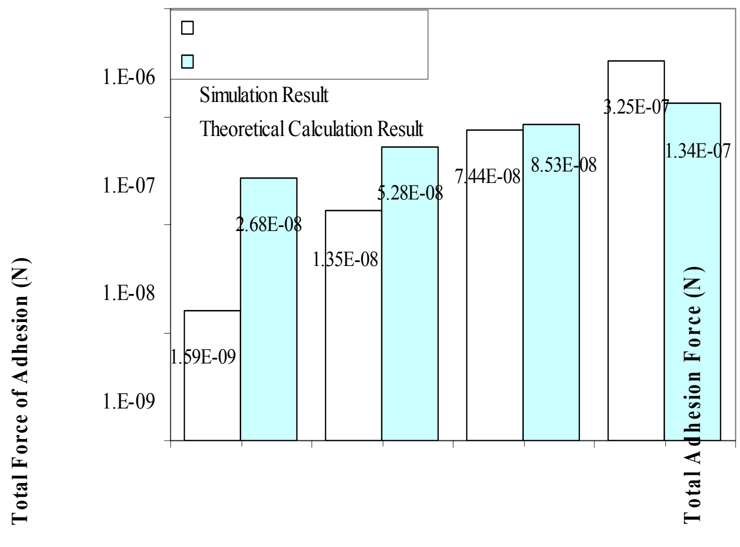


Figure 6: Effect of surface tension oil at 0^0-particle size 125-180μm

The inferred force of adhesion using the particle adhesion model was found to be in the range of 1.6×10^{-9} to 3.3×10^{-7} N. Consistent with the results from the wind tunnel experiments, the inferred adhesion force increased with particle size, oil content, viscosity and surface tension of oil. Force of adhesion increased with particle size since all three types of interaction (van der Waals, electrostatic and capillary) are directly proportional to the particle size. The increase in adhesion force at higher oil content can be attributed to higher hydrophobic interactions. The increase in adhesion force at higher viscosity of oil can be explained as a result of higher drag force needed to remove the seasoning from the chip surface for higher viscosity oil. Higher adhesion force at higher surface tension of oil is believed to be due to larger capillary force of interaction.

The contact angle of oil on the chip surface was measured by photographing an oil drop resting on the chip surface. The roughness factor (ratio of area of chip and a smooth surface of the same dimensions) was inferred from the measurement of the amount of oil retained by the chip and a treated glass slide of the same contact angle. These were then employed to evaluate the capillary force. The calculated capillary force was found to be in the range of 2.7 ×10-8 to 1.3 ×10-7 N which is much larger than both the van der Waals (10-14 - 10-9 N) and electrostatic (10-11 -10-10 N) forces. Inferred adhesion forces from the wind tunnel experiments compared well with the calculated capillary force indicating thereby that van der Waals and electrostatic forces do not significantly contribute to the total adhesion force.



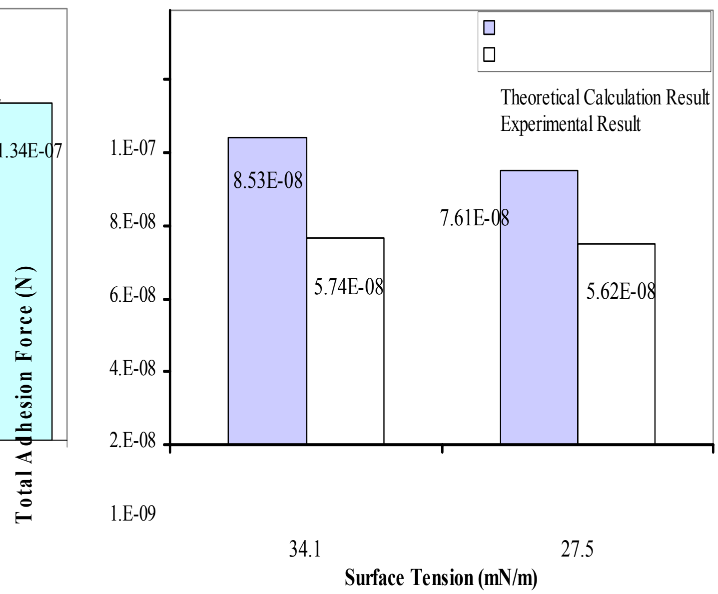


Figure 6: Effect of surface tension oil at 0⁰, particle size 125-180µm

Figure 7: Plot of comparison between estimated total theoretical adhesion force and the simulation result adhesion force based on experimental data for effect of particle size (left) and surface tension of oil (right).

As can be seen from Figs. 7 and 8, the total theoretical interaction force showed relatively the same qualitative trend as the experimental data for seasoning of different particle sizes as well as soybean oil with different surface tensions.

Conclusion

Laboratory scale tortilla chip process was optimized by comparing the blister size distribution and visual appearance with commercial dorito product. Tortilla chips were made by sheeting and baking masa dough (300°C for 100-110 s) followed by frying in soybean oil (190°C for 40 s). Wind tunnel experiments were carried out to characterize the adhesion of seasoning with tortilla chip in which the loss of seasoning when a tortilla chip with monolayer of seasoning was exposed to air at different flow rates were measured. Based on boundary layer theory, the inferred adhesion force of seasoning particle and chip surface from the experimental data was in the range of 1.6×10^{-9} to 3.3×10^{-7} N. Results showed that adhesion strength increases with increasing seasoning particle size (32 - 300µm), oil content of tortilla chip (24-32%), viscosity of oil (µ=55.9-72.2 cP) and surface tension of oil (σ= 27.5 – 34.1mN/m). Predicted van der Waals and electrostatic adhesion forces were found to be much smaller than the inferred forces. However, the predicted capillary forces based on measured values of contact angle and surface roughness compared favorably with the inferred adhesion forces. The total theoretical interaction force showed relatively the same qualitative trend as the experimental data for different particle sizes and surface tensions.

Publications and Presentations:

Enggalharjo, Merysia. Adhesion of Dry Seasoning Particles Onto Tortilla Chips, M.S. Thesis, Purdue University, May 2004.

Enggalharjo, M., Kaizer,K., Foley, S. and Narsimhan, G., Adhesion of Seasoning Particles Onto Snack Food Surfaces, Paper presented at the Annual American Institute of Chemical Engineerings Meeting, San Fransisco, CA, Nov. 2003.