Characterization of Cellulose Acetate Films: Formulation Effects on the Thermomechanical Properties and Permeability of Free Films and Coating Films

Please Note: This report is the unedited version of the publication that was featured in *Pharmaceutical Technology*, V 33, N 3, pp. 88-100, 2009.

Jinghua Yuan*, Doug Dunn, Nancy M. Clipse, and Ray J. Newton, Jr.

Formulation Products Lab
Pharmaceutical Formulations Group
Eastman Chemical Company
Kingsport, Tennessee 37662

Jinghua Yuan: Principal Technical Service Representative
Tel: (423) 229-8627
Fax (423) 224-0414
jinghua@eastman.com

**To whom all correspondence should be addressed.*

Abstract

Cellulose acetate (CA) is one of the most suitable semipermeable membranes for osmotic drug delivery systems. Understanding formulation variable effects on the properties, especially permeability of the films, is a key to design a robust formulation to reduce variation of a finished product. This study deals with the investigation of plasticizer (PEG 3350) and water effects on film properties, particularly addressing how a small change in acetyl content in CA polymer over a range of about 1.0% affects the permeability of the coating films. Results show that with increasing the plasticizer level, the mechanical strength of the free films decreased, and the permeability of the films increased. Although acetyl content didn't significantly affect the free films, it was found that the permeability of coating films increased with decreasing acetyl content in CA polymers and the effects were largely dependent on the formulation. With higher plasticizer and water levels in the formulation, the acetyl content only slightly affected the permeability of the coating film.

Introduction

Cellulose acetate (CA) is a polymeric excipient widely used in pharmaceutical dosage forms for controlled release (1-5) and taste masking (6-8). Up to now, CA is one of the most suitable polymeric materials as the semi-permeable membrane for osmotic drug delivery systems (9-10).

Osmotic drug delivery systems have many different designs and configurations; however, they mainly consist of tablet core and semi-permeable membrane surrounding the core (11). When designing an osmotic drug delivery system, many factors could affect the release rate of an active needed to be delivered. Selection and design of the semipermeable membrane remain one of great challenges for formulation scientists.

Knowing the relationship between formulation and the resulting film properties is crucial for designing a membrane to control release rate. Some work has been published (12). The authors reported the investigation of the effects of solvent systems (acetone and acetone/water), polyethylene glycol (PEG) molecular weight and level on the properties of CA-free films. Water as a co-solvent in the formulation definitely affected morphology, and ultimately, the properties of the films. The films prepared from acetone were transparent, flexible, stronger, but less permeable to water vapor compared to those films with water as a co-solvent. Meier *et al* published the similar results when they studied the influence of the plasticizer content and film preparation procedure on the morphology, thermal and mechanical properties of cellulose acetate films plasticized with poly(caprolactone triol) (PCL-T) (13). It was demonstrated that the addition of water, a non-solvent, during the membrane casting process was a simple and effective way to change membrane porosity and consequently the drug-permeation profile. When small quantities of non-solvent were used to obtain low porosity membranes, the presence of a plasticizer agent could be used to better modulate drug permeation (14).

In general, as the acetyl content in CA increases, the CA film permeability decreases, solvent resistance increases, and the glass transition temperature increases (15). However, for the small variation within the specification of CA-398-10NF-EP, no study has been found to address the effect of the acetyl content on CA film properties. Although free film properties would provide insights for predicting permeability of the films, applying CA polymer onto a substrate is a final step to assure the release profile as designed. The objectives of this study were to investigate the acetyl content in CA polymer on the film properties, particularly the permeability of free films and coating films; and to study the effects of plasticizer level (PEG 3350) and water level on the properties of free films and coating films.

Materials and Methods

Materials. CA-398-10NF-EP with acetyl content at 39.4% and CA-398-10TG (technical grade) with acetyl content at 40.3% (Eastman Chemical Company, Kingsport, TN) were used in the study. Plasticizer (Pz) investigated was polyethylene glycol 3350 (PEG 3350, Sigma Aldrich, St Louis, MO). High purity acetone (B&J Brand, Burdick & Jackson, Muskegon, MI) and deionized water (NANOpure water system, Barnstead, Van Nuys, CA) were used as the solvent system. When applying CA onto tablets, the coating formulations were the same as those as casting films. The tablets to be coated consisted of 98.5% of POLYOX water-soluble resins with a molecular weight of 5,000,000 (Dow Chemical, Midland, MI), 0.5% of colorant (Sensient Technologies Corp., St. Louis, MO), and 1.0% of magnesium stearate (Mallinckrodt Baker Inc., Phillipsburg, NJ). All of the materials were used as received.

Preparation of CA-free films. The CA-free films were prepared using a solvent evaporation method. Dissolve PEG 3350 in water for 1.5 hours, then add most of needed acetone to the PEG/water solution, and add CA gradually under stirring to the solvent system. After all CA was added, stirring continued for another two hours to allow CA to dissolve completely. Add the remaining needed acetone to the above mixture, and stir for 30 minutes. Degas the CA solution for about three hours, the solution was ready to be used to cast films. The film cast method and procedures can be found in reference (12). The film formulations were developed based on an experiment design; the design space was that water varied from 0.0 -10.0% and the ratio of Pz to polymer varied from 0.00 - 0.29. There were three repeated points (center point) for CA-398-10NF-EP and one center point for CA-398-10TG. The design was constrained with water must be in the formulations whenever Pz presents. Table I lists all of the free films prepared.

Table I. List of CA- Free Films Studied.

Sample I.D.	CA	Pz Level (%)	Pz/CA ratio	Water Level (%)
1	CA-398-10NF-EP	1.68	0.13	5.00
2	CA-398-10NF-EP	1.68	0.13	10.00
3	CA-398-10NF-EP	0.00	0.00	0.00
4	CA-398-10NF-EP	0.00	0.00	5.00
5	CA-398-10NF-EP	3.37	0.29	5.00
6	CA-398-10NF-EP	1.68	0.13	3.00
7	CA-398-10NF-EP	3.37	0.29	4.00
8	CA-398-10NF-EP	1.68	0.13	5.00
9	CA-398-10NF-EP	0.00	0.00	10.00
10	CA-398-10NF-EP	3.37	0.29	10.00
11	CA-398-10NF-EP	1.68	0.13	5.00
12	CA-398-10TG	0.00	0.00	5.00
13	CA-398-10TG	1.68	0.13	5.00
14	CA-398-10TG	1.68	0.13	10.00
15	CA-398-10TG	0.00	0.00	0.00
16	CA-398-10TG	3.37	0.29	5.00
17	CA-398-10TG	1.68	0.13	3.00
18	CA-398-10TG	0.00	0.00	10.00
19	CA-398-10TG	3.37	0.29	10.00

Note: Samples 1, 8, and 11 are repeat runs at the center point of the experimental design.

Characterization of CA-free films. The prepared films were characterized and the film properties, such as, film morphology, glass transition temperature, oxidative and thermal stability, mechanical strength and elongation, contact angle, and water vapor transmission rate, were determined according to the methods described in a paper (12).

Preparation of model tablets. POLYOX with a molecular weight of 5, 000,000, blue dye, and magnesium stearate were blended in a v-blender (The Patterson Kelly Co. Inc, East Stroudsburg, PA) for three minutes with the intensifying bar on for 15 seconds. The above mixture was then compressed into 250.0 mg tablets on a rotary tablet press (D3B 16 station, Manesty, England) under 200 lb compression force.

CA coated on the model tablets. The CA coating formulations at 6.0% solid level were prepared following the same procedures as used to prepare CA- free film except there was no degas step. The coating formulations having four repeat points (center point) for CA-398-10NF-EP and one center point for CA-398-10TG based on the same experimental design as the free films are listed in Table II.

Table II. Coating Formulations.

ID	Which CA	CA (g)	PEG 3350 (g)	Water (g)	Acetone (g)	PEG/CA Ratio	% Water
1	CA-398-10NF-EP	71.05	8.95	66.67	1186.66	0.13	5.00
2	CA-398-10NF-EP	71.05	8.95	133.33	1120.00	0.13	10.00
3	CA-398-10NF-EP	80.00	0.00	0.00	1253.33	0.00	0.00
4	CA-398-10NF-EP	80.00	0.00	66.67	1186.66	0.00	5.00
5	CA-398-10NF_EP	71.05	8.95	66.67	1186.66	0.13	5.00
6	CA-398-10NF-EP	62.02	17.98	66.67	1186.66	0.29	5.00
7	CA-398-10NF-EP	71.05	8.95	40.00	1213.33	0.13	3.00
8	CA-398-10NF-EP	62.02	17.98	53.33	1200.00	0.29	4.00
9	CA-398-10NF-EP	71.05	8.95	66.67	1186.66	0.13	5.00
10	CA-398-10NF-EP	80.00	0.00	133.33	1120.00	0.00	10.00
11	CA-398-10NF-EP	62.02	17.98	133.33	1120.00	0.29	10.00
12	CA-398-10NF-EP	71.05	8.95	66.67	1186.66	0.13	5.00
13	CA-398-10TG	80.00	0.00	66.67	1186.66	0.00	5.00
14	CA-398-10TG	71.05	8.95	66.67	1186.66	0.13	5.00
15	CA-398-10TG	71.05	8.95	133.33	1120.00	0.13	10.00

16	**CA-398-10TG**	**80.00**	**0.00**	**0.00**	**1253.33**	**0.00**	**0.00**
17	**CA-398-10TG**	**62.02**	**17.98**	**66.67**	**1186.66**	**0.29**	**5.00**
18	**CA-398-10TG**	**71.05**	**8.95**	**40.00**	**1213.33**	**0.13**	**3.00**
19	**CA-398-10TG**	**80.00**	**0.00**	**133.33**	**1120.00**	**0.00**	**10.00**
20	**CA-398-10TG**	**62.02**	**17.98**	**133.33**	**1120.00**	**0.29**	**10.00**

Note: Samples 1, 5, 9, and 12 are repeat runs at the center point of the experimental design.

All of the coating runs, with a target coating weight at 10.0 wt% relative to the tablet weight, were performed in a pan coater (COMPU-LAB, Thomas Engineering, Inc., Hoffman Estates, IL) with one spray gun under the processing conditions indicated in Table III.

Table III. Coating Processing Conditions.

Factor	**Condition**
Equipment	12 " Pan coater (COMPU-LAB, Thomas Engineering)
Nozzle	35100-ss
Substrate	250.0 mg tablets
Pan Charge	800.0 g
Inlet temperature	25.0 °C
Air flow rate	175.0 cfm
Pan rotation speed	15.0 RPM
Atomized air pressure	15.0 psi
Spray rate	20.0 ml/min for 5 min; increased to 25.0 ml/min for another 5 min; and maintained at 30.0 ml/min for the rest of the run

800.0 g of tablets were coated in each run, and all coating runs were repeated at least twice.

Testing of CA coated tablets. Eight tablets from each coating run were randomly selected and tested in deionized water at 37 °C to determine water uptake using a standard disintegration tester. At selected time intervals, the tested tablets were taken out, gently dried with a tissue and weighed. The water uptake was calculated by the following equation:

Water uptake at time t = (the tablet weight at time t – the tablet weight at time 0).

Results and Discussions

CA-free film properties.

Effects of plasticizer and water level on CA-free film properties. In this section, discussion is focusing on CA-398-10NF-EP film properties, and comparison of the film properties of CA with different acetyl levels will be discussed in acetyl content effect section.

Appearances of the CA-free films were opaque; except those two films that didn't have water in the formulation, which were transparent. It has been observed that water in the film formulation affects the morphology of the film (13, 16).

The film properties results are organized in table IV, V and VI according to the water content in the formulations.

Table IV. CA-Free Film Properties with 0.00% Pz and 0.00% Water in the Formulations.

No Pz, No water	**CA-398-10NF-EP (39.4% acetyl)**	**CA-398-10TG (40.3% acetyl)**
Tg (°C)	191	189
TGA (air, °C)	334	331
TGA (N_2, °C)	338	336
Tensile strength (mPa)	86	73
% elongation	10.6	6.8
WVTR (g mil/M^2/day)	1583	1539
Contact Angle (deg)	65	66

Table V. CA-Free Film Properties with 5.00% Water in the Formulations.

	Tg (°C)		**T_{10} (air, °C)**		**T_{10} (N_2, °C)**	
Pz (%)	**NF**	**TG**	**NF**	**TG**	**NF**	**TG**
0.00	193	189	333	330	336	334
1.68	187	185	311	307	342	337
3.37	188	188	309	300	347	344

	Contact angle (deg)		Tensile strength (mPa)		% elongation		WVTR (g mil/M^2/day)	
Pz (%)	NF	TG	NF	TG	NF	TG	NF	TG
0.00	58	62	67	69	3.3	3.7	1552	1464
1.68	63	64	45	37*	4.1	2.8*	1599	1777*
3.37	72	64	28	30	5.9	3.3	1678	1669

Note: 1. NF – CA-398-10NF-EP; TG – CA-398-10TG.
2. * The film had defeats which made the film weaker and more permeable.

Table VI. CA-Free Film Properties with 10.00 % Water in the Formulations.

	Tg (°C)		T_{10} (air, °C)		T_{10} (N_2, °C)	
Pz (%)	NF	TG	NF	TG	NF	TG
0.00	192	190	331	327	336	334
1.68	186	183	310	305	344	336
3.37	185	187	291	285	344	337

	Contact angle (deg)		Tensile strength (mPa)		% elongation		WVTR (g mil/M^2/day)	
Pz (%)	NF	TG	NF	TG	NF	TG	NF	TG
0.00	62	55	60	31*	5.7	5.7*	1550	2770*
1.68	63	54	38	36	9.3	9.1	2022	2073
3.37	72	79	25	29	2.5	2.9	1831	2109

Note: 1. NF – CA-398-10NF-EP; TG – CA-398-10TG.
2. * The film had defeats which made the film weaker and more permeable.

MDSC data show that glass transition temperature (Tg) changed from 191 °C without the Pz and water in the formulation to 185 °C with the most Pz and water level in the studied range. The small change suggests that PEG 3350 is not a very effective plasticizer for CA films in the studied range; this is consistent with the study published before (12).

T_{10} (° C, N_2 purge), at which temperature 10% of sample weight is lost, represents the thermal stability of the films; while T_{10} (° C, air purge) represents the oxidative stability of the films. TGA results indicate that Pz and water level didn't have significant effects on thermal and oxidative stability of the films since the temperatures didn't vary greatly with increasing Pz and water level.

Figure 1 displays the mechanical strength of the CA-free films varying with water and Pz level. It is clear that PEG 3350 and water level influence mechanical strength significantly; and PEG 3350 level has the major effect. With increasing PEG level, the films became weaker. This is expected because a plasticizer increases polymer chain mobility, so that mechanical strength decreases. Water functions as a weak plasticizer, so that the film mechanical strength decreased with increasing water in the formulations.

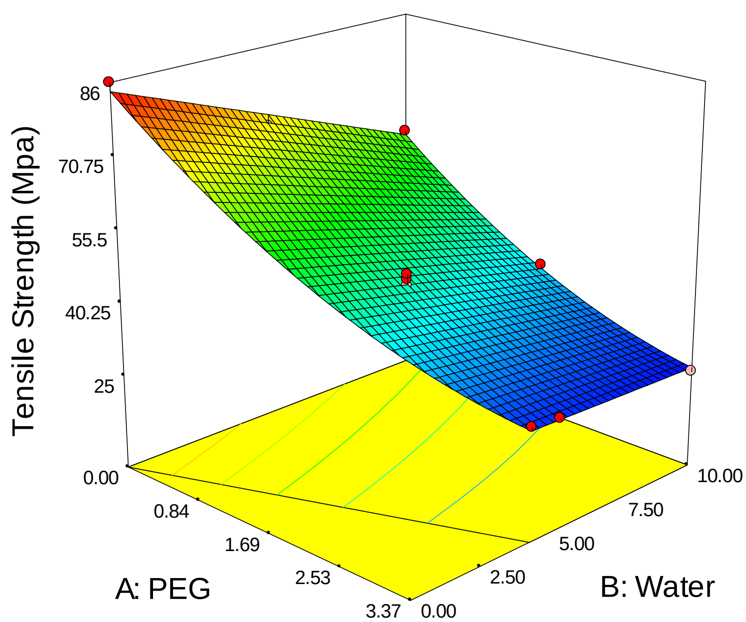

Figure 1. Mechanical strength of CA-free films changes with Pz and water level.

The significant mechanical strength decrease may also be contributed by the morphology of the films. Figures 2 to 5 show the SEM images of the CA-free films. With increasing Pz and water level in the formulations, the number and size of the pinholes were increased significantly.

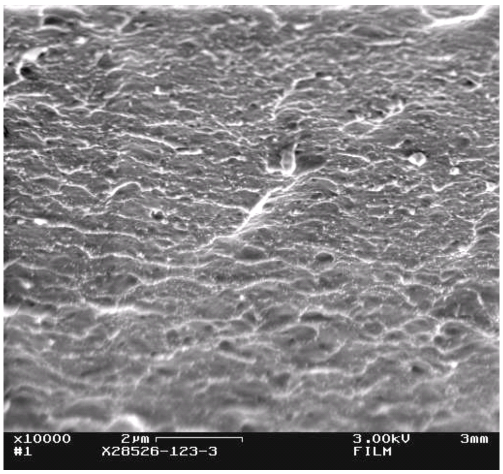

Figure 2. SEM images of the CA film without Pz and water. Left: surface image; right: cross-section image.

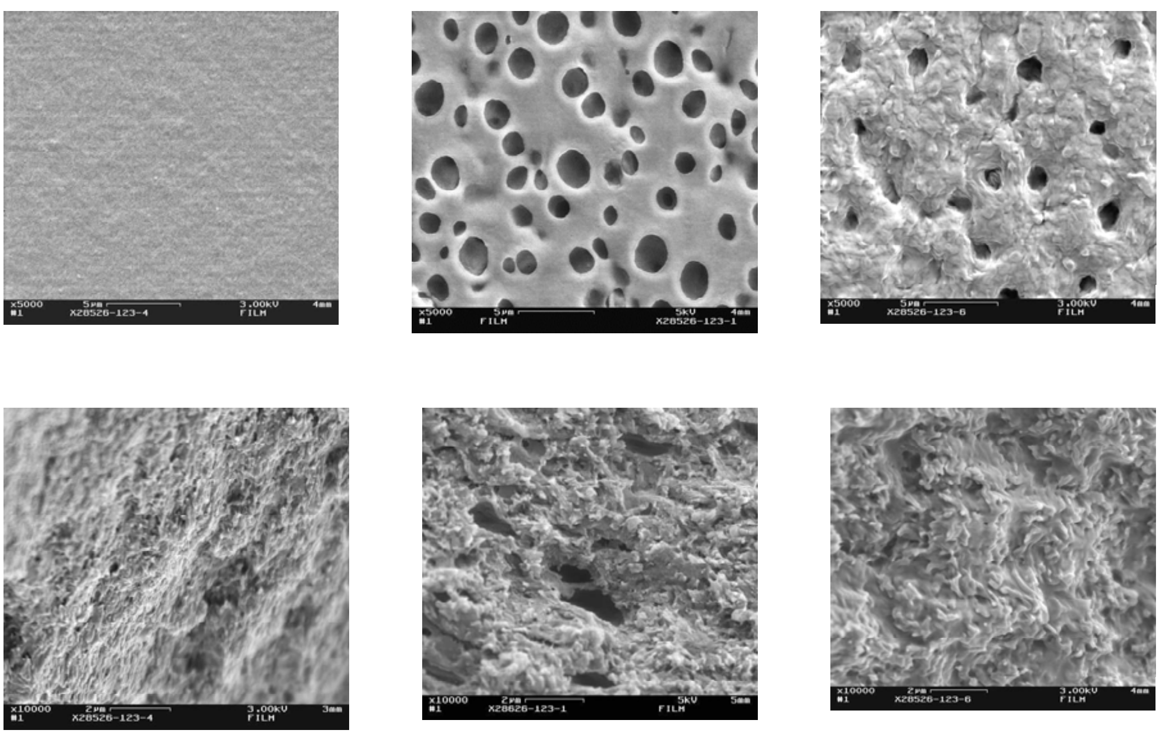

Figure 3. SEM images of the CA films with 5.00% water in the formulations. Top: surface images; bottom: cross-section images. Left: 0.00% Pz; middle: 1.67% Pz; right: 3.37% Pz.

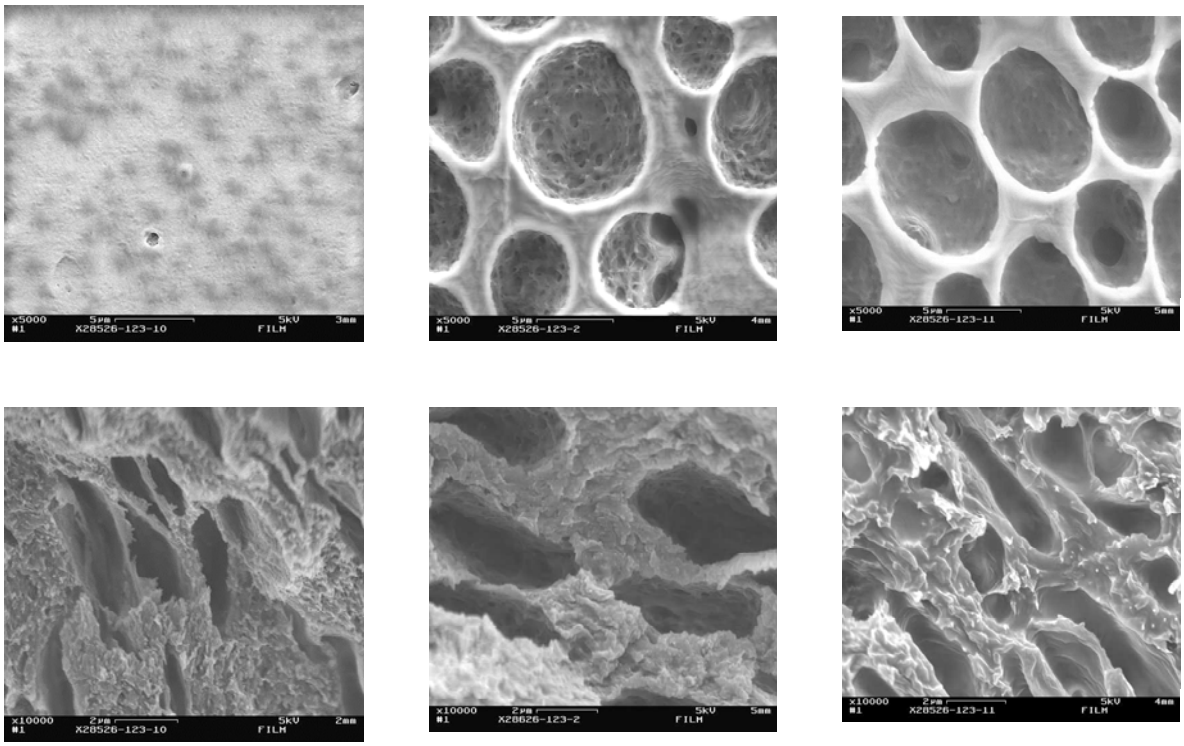

Figure 4. SEM images of the CA films with 10.00% water in the formulations. Top: surface images; bottom: cross-section images. Left: 0.00% Pz; middle: 1.67% Pz; right: 3.37% Pz.

The percentage of elongation reflects the extent to which the films can be stretched, so that it represents the flexibility of a film. Since a Pz increases polymer chain mobility, one would expect Pz level would increase the flexibility of the free films, which results in % elongation increase. However, the data listed in the tables VI, V and VI show that the film was more flexible when no Pz and water existed, and not much difference with Pz and water change. This is further suggesting that PEG 3350 is not an effective plasticizer for the films in the studied range; and bigger and more numerous pinholes with increasing Pz and water also made the films less stretchable.

The wettability of a film is represented by contact angle. The smaller angle means the film has better wettability. In general, the films plasticized with hydrophilic plasticizer exhibit increased wettability; while the films plasticized with hydrophobic plasticizer show decreased wettability. The data in tables IV, V and VI show that PEG and water level didn't affect the wettability of the films in the studied range.

Permeability of a film is a key factor to consider when designing a film formulation. Water vapor transmission rate (WVTR) is a commonly used measurement to determine the permeability of a film. Figure 5 shows the WVTR of CA films changes with Pz and water level. It is not surprising that PEG 3350 alone didn't affect WVTR significantly; as discussed before, PEG 3350 is not a very effective plasticizer for CA in the studied range. However, with the interaction of water and PEG 3350, WVTR increased with PEG 3350 and water level, and significantly when water was more than 5% in the formulations. This can be explained by morphologies of the films. SEM images show that the number and size of pinholes increased greatly with water and PEG 3350 level (see Figures 2 to 4).

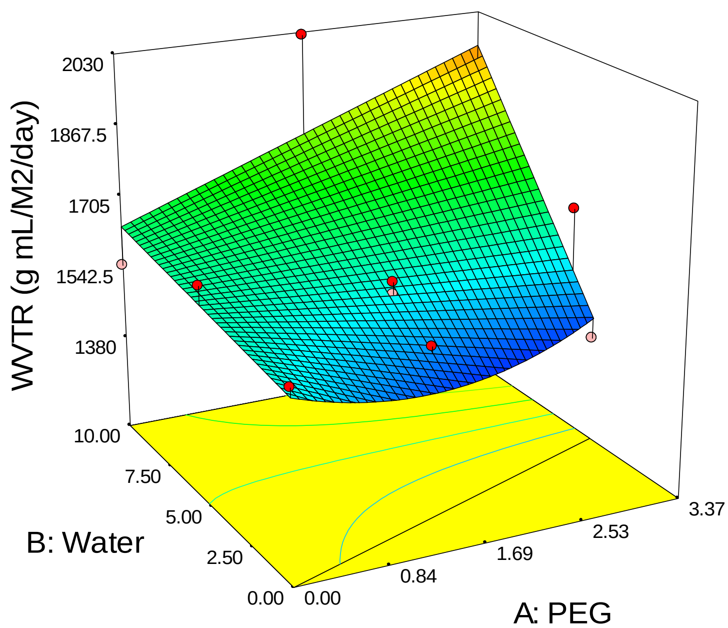

Figure 5. WVTRs of CA-free films changes with Pz and water level.

<u>Acetyl effects on CA-free film properties.</u> CA-398-10TG with acetyl content at 40.3% was also used in the film study to determine how a change in acetyl content over a range of about 1.0% affects film properties. Comparison of the film properties between CA-

398-10NF-EP (NF, 39.4% acetyl) and CA- 398-10TG (TG, 40.3% acetyl) suggested that no significant acetyl effect on free film properties can be observed in the studied range (see table IV, V and VI).

Permeability of CA coating on tablets. CA was coated on model tablets prepared as previously described. The water uptake was measured as a function of time. It was observed that the water uptake increased linearly with time. This is due to the nature of POLYOX resin, which will retain water and swell after absorbing water penetrating through CA film. When the coating film was no longer able to hold the inside pressure, the film ruptured and the experiment was terminated. The slope of the water uptake curve represents water uptake rate (g/min); it changes with formulation factors, such as the plasticizer (Pz) level and water level.

Design expert software (Design Expert V7., Stat-Ease, Inc., Minneapolis, MN) was used to analyze the water uptake data. Based on the data, a model was established to predict water uptake rate. The fitted model is as follows:

Water uptake rate (g/min) =
+3.26145E-003
+2.90396E-005 * PEG + 6.90834E-005 * PEG^2
-2.35306E-005 * Water + 1.98277E-006 * Water^2
+9.80461E-006 * PEG * Water
-7.15720E-005 * Acetyl

where: PEG is the Pz concentration in the formulation in % (0.00% to 3.37%); water is the water concentration in the formulation in % (0.00% to 10.00%); acetyl is the % acetyl content of the CA polymer (39.4% to 40.3%).

The fitted model indicates that the more Pz in the formulation, the higher water uptake rate. It is also true for water level factor. PEG is the major influencing factor. Figure 6 shows the relationships visually.

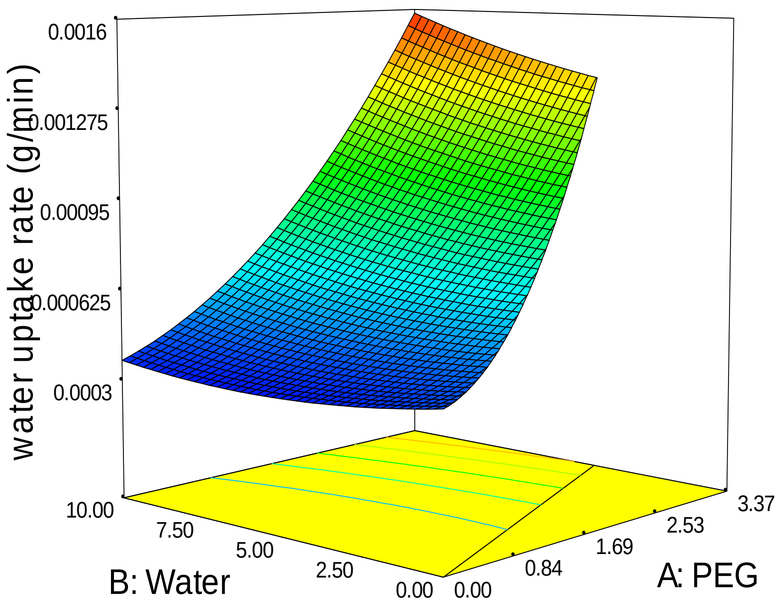

Figure 6. Water uptake rate changes with Pz and water level.

Figure 7 shows water uptake predicted from the model at Pz=3.00%, water =5.00%, acetyl = 40.3% and acetyl = 39.4%. The difference in the water uptakes between the CAs with these two acetyl levels is 5.7 %. The difference in water uptake by acetyl content is calculated by the following equation:

Difference in water uptake (%) = (water uptake at acetyl=39.4% - water uptake at acetyl= 40.3%) / water uptake at acetyl=39.4% *100%

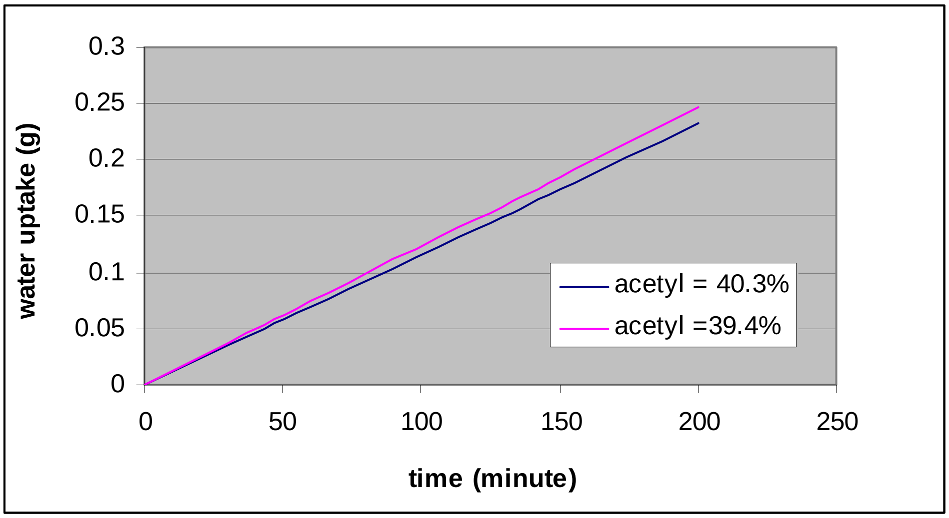

Figure 7. Predicted acetyl effects on water uptake at Pz=3.00% and water =5.00%.

It should be noted that acetyl effects on the water uptake decreases significantly with increasing Pz and water in the formulations. Table VII lists the difference in water uptake by acetyl content, assuming the coating processing conditions are controlled precisely the same.

Table VII. Water Uptake Difference between the CAs with Two Levels of Acetyl Content (39.4% and 40.3%).

Water Level (%)	Pz Level in Total(%)	PEG/CA (%)	Difference in Water Uptake (%)
5.00	0.50	3.4	15.0
	1.67	12.6	9.4
	3.37	28.9	4.9
10.00	0.50	3.4	13.5
	1.67	12.6	8.1
	3.37	28.9	3.7

So, it is crucial to understand how formulation factors affect the permeability of the coating film and the release rate of a finished product in order to design a formulation to eliminate the variations from raw materials.

Conclusions

Understanding formulation factor effects on free film and coating film properties would provide guidelines for selecting a formulation in the early design stage of developing semi-permeable membranes. The results from this study demonstrated that formulation factors, such as plasticizer and water level, signifantly affect free film properties and coating performance. With increasing plasticizer level, the mechanical strength of the free films decreased and the permeability of the films increased. With the interaction of plasticizer and water, the effects on the properties of free films were even greater. Although there were no significant differences in free film properties between CA-398-10NF-EP and CA-398-10TG, it was found that the permeability of coating films increased with decreasing acetyl content in CA polymers. The acetyl content over a range of about 1.0% affected permeability of coating films at some degree and the effects were largely dependent on the formulation. With higher plasticizer level and water level in the formulation, the acetyl content only slightly affected the permeability of the coating film. This study demonstrates that it is important to design a robust formulation to reduce the variability of a finished product. It should be realized that besides formulation factors, processing conditions are key controls in assuring product quality and keeping the release profile of a product in a desirable range.

References

1. N. Ramakrishna and B. Mishra, "Plasticizer Effect and Comparative Evaluation of Cellulose Acetate and Ethylcellulose-HPMC Combination Coatings as Semipermeable Membranes for Oral Osmotic Pumps of Naproxen Sodium," *Drug Development and Industrial Pharmacy* **28**(4), 403-412 (2002).
2. G. Deepak and P. Kilambi, "The Fabrication and Evaluation of the Formulation Variables of a Controlled-Porosity Osmotic Drug Delivery System," *Pharmaceutical Technology* **27** (9), 58-68 (2003).
3. S.N. Makhija and P.R. Vavia, "Controlled Porosity Osmotic Pump-based Controlled Release Systems of Pseuoephedrine I. Cellulose Acetate as a Semipermeable Membrane," *Journal of Controlled Release* **89**, 5-18 (2003).
4. T. Guyonnet, C. Brossard, and D. Lefort des Ylouses, "Prolongation of Release of Theophylline Derivatives from Cellulose Acetate-based Tablets," *Journal de Pharmacie de Belgiue* **45** (2), 111-119 (1990).
5. O.Y. Abdallah, N.A. Boraie, and V.F. Naggar, "Preparation and Evaluation of Metformin Hydrochloride Controlled-Release Tablets," *S.T.P. Pharma* **4**(1), 15-20 (1988).
6. M. Corbo, J. Desai, M. Patell, and R. Warrick, "Taste Masking Coating Composition Based on Methacrylate polymer and Cellulose Ester," World Patent No. 2001080826 (2001).
7. M.R. Hoy and E.J. Roche, "Taste Mask Coatings for Preparation of Chewable Pharmaceutical Tablets," US Patent No. 5489436 (1996).
8. E.J. Roche, "Taste-Masking and Sustained-Release Coatings Containing Cellulose Derivatives for Pharmaceuticals," Europe Patent No. 459695 (1991).
9. R.K. Verma, D.M. Krishna, and S. Gard, "Formulation Aspects in the Development of Osmotically Controlled Oral Drug Delivery Systems," *Journal of Controlled Release* **79**, 7-27 (2002).
10. G. Santus and R.W. Baker, "Osmotic Drug Delivery: a Review of the Patent Literature," *Journal of Controlled Release* **35**, 1-21 (1995).
11. A.M. Kaushal and S. Garg, "An Update on Osmotic Drug Delivery Patents," *Pharmaceutical technology* **27**(8), 38-97 (2003).
12. J. Yuan, P.P. Shang and S.H. Wu, "Effects of Polyethylene Glycol on Morphology, Thermomechanical Properties, and Water Vapor Permeability of Cellulose Acetate- Free Films," *Pharmaceutical Technology* **25**(10), 62-74 (2001).
13. M.M. Meier, L.A. Kanis, J.C. de Lima, Alfredo T.N. Pires, and V. Soldi, "Poly(caprolactone triol) as Plasticizer Agent for Cellulose Acetate Films: Influence of the Preparation Procedure and Plasticizer Content on the Physico-chemical Properties," *Polymers for Advanced Technologies* **15**(10), 593-600 (2004).
14. M.M. Meier, L.A. Kanis, and V. Soldi, "Characterization and Drug-permeation Profiles of Microporous and Dense Cellulose Acetate Membranes: Influence of Plasticizer and Pore Forming Agent," *International Journal of Pharmaceutics* **278**, 99-110 (2004).

15. J. Yuan and S.H. Wu, "Sustained-Release Tablets via Direct Compression: A Feasibility Study Using Cellulose Acetate and Cellulose Acetate Butyrate," *Pharmaceutical Technology* **24**(10), 92-106 (2000).
16. J. Yuan and J. Zhu, "Investigation of the Opaqueness in Cellulose Acetate 398-10NF Free Films: Water Effects," *Eastman Technical Report* **TR-2005-04061** (2005).

Table and Figure Legends

Table I. List of CA- Free Films Studied. (Yuan, Jinghua)
Table II. Coating Formulations. (Yuan, Jinghua)
Table III. Coating Processing Conditions. (Yuan, Jinghua)
Table IV. CA-Free Film Properties with 0.00% Pz and 0.00% Water in the Formulations. (Yuan, Jinghua)
Table V. CA-Free Film Properties with 5.00% Water in the Formulations. (Yuan, Jinghua)
Table VI. CA-Free Film Properties with 10.00 % Water in the Formulations. (Yuan, Jinghua)
Table VII. Water Uptake Difference between the CAs with Two Levels of Acetyl Content (39.4% and 40.3%). (Yuan, Jinghua)

Figure 1. Mechanical strength of CA-free films changes with Pz and water level. (Yuan, Jinghua)
Figure 2. SEM images of the CA film without Pz and water. Left: surface image; right: cross-section image. (Yuan, Jinghua)
Figure 3. SEM images of the CA films with 5.00% water in the formulations. Top: surface images; bottom: cross-section images. Left: 0.00% Pz; middle: 1.67% Pz; right: 3.37% Pz. (Yuan, Jinghua)
Figure 4. SEM images of the CA films with 10.00% water in the formulations. Top: surface images; bottom: cross-section images. Left: 0.00% Pz; middle: 1.67% Pz; right: 3.37% Pz. (Yuan, Jinghua)
Figure 5. WVTRs of CA-free films changes with Pz and water level. (Yuan, Jinghua)
Figure 6. Water uptake rate changes with Pz and water level. (Yuan, Jinghua)
Figure 7. Predicted acetyl effects on water uptake at Pz=3.00% and water =5.00%. (Yuan, Jinghua)