Chemical Education Journal (CEJ), Vol. 13, No. 1 /Registration No. 13-9/Received July 29, 2009.
URL = http://chem.sci.utsunomiya-u.ac.jp/cejrnlE.html

How Thick is the Laminated Aluminum Foil of Flexible Food Packages and How Many Atomic Layers are There? Students' Quantitative Problem Solving through Complexometric Titration Experiments

Shui-Ping YANG* and Chung-Chia LI

Department of Chemistry, National Changhua University of Education, Changhua, Taiwan
*yangsp@cc.ncue.edu.tw

Keywords: Complexomeric Back Titration, Atomic Layer, Laboratory Instruction, Problem-Based Learning, Hands-On Learning, and Chemometrics

Abstract
Chemistry-major freshmen often learn problem-solving skills in the classroom rather than in the laboratory. The problems that are usually given by teachers or from textbooks are almost virtual-situation rather than real-world. In this study, we provided our students with a real-world problem on the thickness and the atomic layer of laminated aluminum foil. This study includes four main facets: (i) Developing teaching materials; (ii) Describing strategies of problems solving; (iii) Examining students' problem solving; and (iv) Analyzing students' learning feedback. This study concludes: (a) Teacher-developed experiments are suitable as real-time teaching materials for students' hands-on learning for general and analytical chemistry laboratories; (b) In term of laminated aluminum foil using four flexible food packages as samples determined by the teacher and students, the thicknesses range 0.000549−0.000652 cm (4.59−6.52 μm) and 0.000480−0.000688 cm (4.80−6.88 μm), as well as show 27100-32200 and 22500−32600 atomic layers, respectively; (c) Student's learning feedback reveal that the overwhelming majority of students have positive responses in cognitive domain, affective domain and science process skills.

Introduction

The laminated aluminum foil of flexible food packages can be readily available to everyone, in everywhere, and in every day. It is widely used as high barrier material to prevent oxygen gas, water vapor and ultraviolet light transmissions for the food, beverage, medicine, and computer packaging. Such packages are commonly constructed with one layer or more of the aluminum foil, plastic and/or paper, and adhesive. How thick is the laminated aluminum foil of flexible food packages? How many atomic layers are there? These interesting problems make students curious to discover the answers.

For motivating student learning, common household products have been used as reagents and materials in the chemistry laboratory. Some of them have recently been compiled in general chemistry laboratory textbooks [such as 1-2]. Consumer products used as assays in the textbooks include white vinegar and antacid for acid-base titration [3-7]; bleach and vitamin tablets for oxidation-reduction titration [6-8]; aspirin tablets and cola drinks for spectrophotometry [3-4]. Consumer products, such as commercial antacid, galvanized iron nails, cereal, powdered drink mixes, imposter perfumes, malted barley, and sports drinks, have been used for qualitative analysis [9-16]. Flexible food packages have been not mentioned in either chemical laboratory manuals or chemical education literature.

Determinations of the thickness and the number of atomic layer in a very thin film could motivate students' learning about the science in microscale and nanoscale materials. Such studies have been adapted as teaching materials. The thicknesses of zinc coating on galvanized irons are 1.43–6.44 x 10^{-4} cm (1.43−6.44 μm) [10]. The film thickness of a Shampoo bubble is 10^{-6} cm (0.01 μm, 10 nm) [17]. The thickness of Au film is in the range of 8.91–32.88 x 10^{-7} cm (0.00891–0.03288 μm, 8.91–32.88 nm) [18]. The shell thickness of the copper-clad cent is 1.16 x 10^{-3} cm (11.6 μm) [19]. The average value for the oxide thickness on aluminum metal is 4.2 x 10^{-7} cm (0.0042 μm, 4.2 nm) [20]. The thickness of vinyl acetate content of packaging film is 1.3–1.5 x 10^{-4} cm (1.3–1.5 μm) [21]. However, only one article reported that the zinc coating on galvanized irons has 18500−64900 atomic layers, which is determined using a gasometric assembly and through a strategy of quantitative problem solving [10].

Chemistry-major freshmen often learn problem-solving skills in the classroom rather than in the laboratory. The problems that are usually provided by teachers or from textbooks, are almost virtual-situation rather than real-world, such as a quantitative problem solving and cross-proportions [22-23]. Recently, real-world problem solving has been integrated into general chemistry laboratory, such as zinc coating on galvanized iron [10], carbohydrate analysis of bananas, prompted inquiry-based learning, seawater analysis, and Mentos and scientific method, investigating the stability of benzoyl peroxide [24-28]. In this article, we provided the students with a real-world problem requiring the complexometric back titration to determine atomic layer of laminated aluminum foil through two different strategies of quantitative problem solving.

This article includes four facets: (i) Adapting teacher-developed experiments with complexometric back titration as teaching materials and guiding students through laboratory instruction to discover the thickness of laminated aluminum foil; (ii) Describing strategies of problem solving about the number of atomic layers of laminated aluminum foil; (iii) Displaying the thickness and the number of atomic layers from students' and teacher's data processing, and evaluating teacher-developed experiments and examining students' problem solving; and (iv) Qualitatively analyzing students learning feedback.

Instructional Strategies and Teaching Materials

Our instruction strategies are divided into four parts: (i) a recitation of content knowledge, (ii) hands-on learning associated with data processing, (iii) quantitative problem solving through discussion, and (iv) homework for answering post-lab questions. During hands-on learning and data processing, our students spend one 3-hr session conducting given procedures by complexometric back titration to determine the thickness of laminated aluminum foil using two independent protocols. In the course of quantitative problem solving, the students take a 1-hr session and are guided by two different strategies with discussion to solve the problems on atomic layers. The instructional strategies with a systematic table as well as time required and group tasks are detailed in Appendices of Supporting Materials.

Forty-eight chemistry-major students engaged this activity in department of chemistry at NCUE in Taiwan during the spring 2007 semester. They were assigned to work in a group of two students. Student groups chose their partners. Each group needed to carried out two independent protocols and completed two different problem-solving. Students' age is most of 18 year old. They have 26 males (54%) and 22 females (46%). Most students were interested in chemistry. An instructor and a TA guided the students for the laboratory instruction.

In this activity, our students solved two problems on 'How thick?' and 'How many atomic layers?' Students must be first determined in the thickness and then solved the number of atomic layers. To determine the thickness, the aluminum quantity of a known area is needed. To obtain the quantity, we developed novel experiments with two independent protocols. For the laboratory instruction, teacher-developed experiments were adapted as teaching materials. Student handout consists of seven sections, as detailed in Supporting Materials. Below is a brief description.

- Problems –introducing two problems;
- Content Knowledge – describing (a) laminated aluminum foil and structure, flexible food packaging, and so on; (b) aluminum analysis, and summaries of the sequence and schematic quantities of metallic ions; and (c) the atomic packing structures;
- Hazards – giving safety precautions for hazardous chemicals;
- Waste Disposal – providing two ways for waste handling;
- Good Practices – providing suggestions of four good practices;
- Experimental Procedures – dividing into six parts: reagent preparation, sample preparation, preliminary, exact, and blank complexometric back titrations, and calculation of aluminum quantity.
- Quantitative Problem Solving through Discussion – using two different strategies to solve the problem of atomic layers.

Before adapting student handout, teacher-developed experiments with complexometric back titration have been evaluated by chemometrics and had passed the evaluation in determining the thicknesses. The evaluation method and its result are detailed in the Appendices of Supporting Materials. Below is the outline of teacher-developed procedures. Detailed procedures are presented in Student Handout of Supporting Materials.

- Part A: Reagent Preparation – preparing 3.0 M NaOH, 1.0 M HCl, 0.1000 M EDTA standard solution, 0.01000 M standardized zinc solution, pH 5.0 and pH 7.0 buffer solutions, 0.2 % xylenol orange and Eriochrome Black T indicators.
- Part B: Sample Preparation – dissolving an indicated area of laminated aluminum foil in sodium hydroxide solution and diluting it to a given volume with deionized water.
- Part C: Preliminary Complexometric Titration - dividing this titration into two different protocols based on metallic indicators and corresponding pH values. Preliminary titration is used to estimate a suitable volume of sample solution used in the next part.
- Part D: Exact Complexometric Titration – dividing into two different protocols. Exact titration is used to determine the quantity of aluminum and non-aluminum metals in the sample solution.
- Part E: Blank Complexometric Titration – dividing into two different protocols. Blank titration is used to determine quantities of non-aluminum metals in the blank solution.
- Part F: Calculation of Aluminum Quantity – calculating the aluminum quantity (excluding non-aluminum metals) of laminated aluminum foil.

After calculating the aluminum quantity, students solved the two problems about the thickness and the number of atomic layers of laminated aluminum foil. The process of problem solving about the number of atomic layers includes identifying the problem, gathering information, collecting and analyzing data, proposing a solution, and checking the answer. Students applied two different strategies to solve the number of atomic layers. Strategy A begins with an atomic packing structure involving the radius of atoms. Strategy B starts with the mass of a unit cell using the density of the metal. Detailed problem-solving processes are presented in Appendices of Supporting Materials.

Results and Discussion

In this paper, we determined the aluminum quantity by two independent protocols using xylenol orange at pH 5.0 and Eriochrome Black T at pH 7.0, respectively. Four flexible food packages − chocolate package (Ch Package), instant coffee package (IC Package), dry food package (DF Package), and Tetra Pak™ package (TP Package) − were used as samples. Evaluation methods for students' and teacher's results were divided into five phases: (i) Teacher-developed experiments as evaluated by chemometrics; (ii) Teacher's results from two different protocols associated with two different strategies of problem solving are compared by different percentages; (iii) Students' results are also compared by different percentages;

(iv) Students' problem solving for atomic layers is examined by chemometrics; (v) Students' learning feedback are summarized into categories and evaluated by the qualitative analysis upon cognitive domain, affective domain, psychomotor domain, and science process skills.

In the first and second phases, evaluating teacher-developed experiments and comparing teacher's data processing with two problem-solving strategies are detailed in Appendices of Supporting Materials. The results indicated that teacher-developed experiments are suitable as real-time teaching materials for students' hands-on learning for general and analytical chemistry laboratories. Additionally, the aluminum thickness of the four samples ranges 0.000549-0.000652 cm (5.49−6.52 μm). These aluminum foils have 27100-32200 atomic layers.

In the third phase, the students apply teacher-developed experiments for determining the thickness and the number of atomic layers applying the four samples. They also use two different strategies to solve the problem on atomic layers. Table 1 shows the thickness from students' data processing and the atomic layers from students' problem solving.

Table 1: Thickness and Atomic Layers Obtained from Students

Samples	Thickness / μm			Atomic Layers using Strategy A			Atomic Layers using Strategy B		
	pH 5	pH 7	Dif. %	pH 5	pH 7	Dif. %	pH 5	pH 7	Dif. %
Ch Package	5.38	6.07	-11.4	32600	29000	12.4	22700	29900	-24.1
IC Package	4.91	4.80	2.3	23600	23300	1.1	22500	23200	-2.8
DF Package	6.55	6.88	-4.7	29100	29000	0.4	29800	29000	2.6
TP Package	6.30	6.57	-4.1	30800	26400	16.6	30800	24400	26.5

Students' data analyses show that the aluminum thickness of the four samples ranges 0.000480−0.000688 cm (4.80−6.88 μm). These aluminum foils have 22500−32600 atomic layers. Moreover, more than half of different percentages of the thickness and the number of atomic layers between two independent protocols are less than 5%. Students obtained a wider range in the thickness and the number of atomic layers relative to that obtained by the teacher.

In the fourth phase, the number of atomic layers from students' problem solving using two different strategies is compared by chemometrics, as presented in Table 2.

The two-tailed *t* test indicates that there are no differences in average of the number of atomic layers between two independent protocols from students' quantitative problem solving using the two strategies. Additionally, the one-sided *F* test shows that there are almost no differences in the results of students' problem solving between the two protocols. Based on the chemometrics, teacher-developed experiments are suitable as student's hands-on teaching materials for solving the problem on the number of atomic layers of laminated aluminum foil.

In the fifth phase, students' learning feedback is summarized into four categories: cognitive domain, affective domain, psychomotor domain, and science process skills and

Table 2: Comparison of Atomic Layers between Independent Protocols

Strategy	Sample	pH 5 No.[a]	pH 7 No.[a]	pH 5 Mean	pH 7 Mean	SD Dif.[b]	*t* Value	*p* Value	*F* Value	*p* Value
A	Ch Package	2	5	32600	29000	-535	0.836	0.427	0.264	0.849
	IC Package	4	5	23600	23300	-396	1.165	0.271	12.611	0.004**
	DF Package	4	4	29100	29000	-3668	0.026	0.980	1.517	0.329
	TP Package	4	4	30800	26400	-3615	1.477	0.174	4.634	0.059
B	Ch Package	2	5	22700	29900	4235	1.207	0.262	62.204	0.000***
	IC Package	3	3	22500	23200	1180	0.557	0.595	2.544	0.194
	DF Package	5	3	29800	29000	-92	1.368	0.204	0.379	0.861
	TP Package	4	4	30800	24400	-3122	2.173	0.058	3.965	0.078

[a]pH 5 No. and pH 7 No. stand for effective sample sizes for the two protocols. [b]Difference of the standard deviation. **This value is significant at $p < .01$. ***This value is significant at $p < .001$.

evaluated by the qualitative analysis − positive response, negative response, and combination of positive and negative responses, as detailed in Appendix of Supporting Materials. Below are the summarizations of students' learning feedback.

Cognitive domain: Students understand the relationship between metal indicators and pH conditions, the principle of complexometric back titration, and the application of blank titration. Students comprehend that the sequence of adding various solutions is very important. Students obtain knowledge about laminated aluminum foil and get to know its widespread applications in everyday products. Students also acquire crystal structure and learn about the relationship between the thickness and the number of atomic layers. **Affective domain:** These teacher-developed experiments can engage students' interest because of analyzing everyday product, flexible food packages. Students are surprised at solving the problem on the number of metallic atomic layers using non-professional analytical instruments. Students consider that these experiments require fervent, patient, circumspection and they have to go through complicated and time-consuming procedures. **Psychomotor domain:** Students become proficient in complexometric back titration, and in making use of highly accurate and precise equipment. On the other hand, students failed many times in conducting experiments since the pH of the solution to be titrated was not carefully controlled. **Science process skills:** Students learn more chemistry knowledge due to group discussion, hands-on, and searching information. Students also gain ideas and suggestions in the course of group discussion, however, they consider that the calculation process need not go though much thinking because they just follow the instructor's direction.

Conclusions

By evaluating teacher-developed experiments and examining students' problem solving, we concluded that the experiments using two independent protocols are suitable as real-time teaching materials for general and analytical chemistry laboratories in solving the problems on the thickness and the number of atomic layers of laminated aluminum foil.

The thicknesses of laminated aluminum foil of four flexible food packages from the teacher's and students' data processing range 0.000549−0.000652 cm (5.49−6.52 μm) and 0.000480−0.000688 cm (4.80−6.88 μm), respectively. The number of atomic layers of laminated aluminum foil from the teacher's and students' problem solving show 27100-32200 and 22500−32600, respectively. Moreover, students obtained a wider range in the thickness and the number of atomic layers relative to the teacher.

According to the qualitative analysis of students' learning feedback, the laboratory instruction using our novel teacher-developed experiments reveal that the overwhelming majority of the students have positive responses in the cognitive domain, affective domain and science process skills; whereas the number of positive responses in psychomotor domain are almost equal to that of negative responses.

Acknowledgments

The authors thank the National Science Council of Taiwan for financially supporting this research by grant NSC 95-2511-S-018-013, and Chai-Jyi Liu for helpful suggestions and Meng-Hstu Tu for enthusiastic assistance.

Supporting Materials

Supporting Materials including Appendices for the text and Student Handout (including student lab report samples) can be downloaded at the following webpage: http://chemed.ncue.edu.tw/yangsp/NICE2009/SM.htm, or available upon request from the corresponding author via email.

Literature

[1] Stratton, W. J.; Steehler, G. A.; Pienta, N. J.; Middlecamp, C. H. *Chemistry in Context Laboratory Manual: Applying Chemistry to Society*, 4th Ed., McGraw Hill: Boston (2003).

[2] Richardson, B. C.; Chasteen, T. G. *Experience the Extraordinary Chemistry of Ordinary Things*, 3rd Ed., John Wiley & Sons: New York (1998).

[3] Greco, T. G.; Rickard, L. H.; Weiss, G. S. *Experiments in General Chemistry: Principles and Modern Applications*, 8th Ed., Prentice Hall: Upper Saddle River (2002), pp 227-234.

[4] Hunt, H. R.; Block, T. F.; McKelvy, G. M. *Laboratory Experiments for General Chemistry*,

4th Ed., Brooks/Cole: CA (2002), pp 97-104 (vinegar), pp 257-264 (cola drink).
[5] Wentworth, R. A. D. *Experiments in General Chemistry*, 7th Ed., Houghton Miffin Company: Boston (2003), pp 225-236.
[6] Bettelheim, F.A.; Landesberg, J. M. *Laboratory Experiments for General, Organic, and Biochemistry*, 4th Ed., Harcourt College Publishers: Fort Worth (2001), pp 239-246 (antacid), pp 507-514 (vitamin).
[7] Zvi, S.; Pike, R. M.; Foster, J. C. *Microscale General Chemistry Laboratory with Selected Macroscale Experiments*, 2nd Ed., John Wiley New York (2003), pp 195-204 (vitamin), pp 249-258 (antacid).
[8] Heasley, V. L.; Christensen, V. J.; Heasley, G. E. *Chemistry and Life in the Laboratory*, 5th Ed., Prentice Hall: Upper Saddle River (2000), pp 79-84 (bleach).
[9] Yang, S.-P.; Tsai, R.-Y. *J. Chem. Educ.*, **83**, 906-909 (2006).
[10] Yang, S.-P. *J. Chem. Educ*. **84**, 1792-1794 (2007).
[11] Hooker, P. *J. Chem. Educ*. **82**, 1223-1225 (2005).
[12] Sigmann, S. B.; Wheeler, D. E. *J. Chem. Educ.* **81**, 1475-1478 (2004).
[13] Sigmann, S. B.; Wheeler, D. E. *J. Chem. Educ.* **81**, 1479-1481 (2004).
[14] Mowery, K. A.; Blanchard, D. E.; Smith, S.; Betts, T. A. *J. Chem. Educ*. **81**, 87-89 (2004).
[15] Pelter, M. W.; McQuade, J. *J. Chem. Educ*. **82**, 1811-1812 (2005).
[16] Drossman, H. *J. Chem. Educ.* **84**, 124-127 (2007).
[17] Chattopadhyay, A. *J. Chem. Educ*. **77**, 1339-1342 (2000).
[18] D'Agostino, A. T. *J. Chem. Educ*. **71**, 892-896 (1994).
[19] Vanselow, C. H.; Forrester, S. R. *J. Chem. Educ.* **70**, 1023-1024 (1993).
[20] King, D. E.; Swartz, W. E., Jr. *J. Chem. Educ*. **64**, 981-983 (1987).
[21] Plummer, B. F. *J. Chem. Educ*. **61**, 439 (1984).
[22] Cohen, J.; Kennedy-Justice, M.; Pai, S.; Torres, C.; Toomey, R.; DePierro, E.; Garafalo, F. *J. Chem. Educ*., **77**, 1166-1173 (2000).
[23] Cook, E.; Cook, R. L. *J. Chem. Educ.* **82**, 1187-1189 (2005).
[24] Davis-McGibony, C. M.; Bennett, R. R.; Bossart II, A. D.; Deal, S. T. *J. Chem. Educ*. **83**, 1543 (2006).
[25] Green, W. J.; Elliott, C.; Cummins, R. H. *J. Chem. Educ*. **81**, 239-241 (2004).
[26] Selco, J. I.; Roberts, J. L., Jr.; Wacks, D. B. *J. Chem. Educ*. **80**, 54-57 (2003).
[27] Eichler, J. F.; Patrick, H.; Harmon, B.; Coonce, J. *J. Chem. Educ.* **84**, 1120-1123 (2007).
[28] Canepa Kittredge, M.; Kittredge, K. W.; Sokol, M. S.; Sarquis, A. M.; Sennet, L. M. *J. Chem. Educ.* **85**, 1655-1657 (2008).