J. Chem. Chem. Eng. 13 (2019) 8-22
doi: 10.17265/1934-7375/2019.01.002

Variable Optimization in Methylmethacrylate Polymerization by Using Design Expert as a Tool for Implementing ICTs in the Polymeric Systems Learning Process

A. Obaya Valdivia[1], C. Montaño Osorio[1], Y. Vargas Rodríguez[1] and L. Giammatteo[1,2]

1. Chemistry Department, Physical Chemistry, FES Cuautitlán UNAM, 54740 México

2. Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), 54740 México

Abstract: Polymers constitute a series of materials that are essential for many processes such as: food transport, packaging and distribution, construction, etc. Hence, it is important to understand the variables that this process depends on. Experimental design is a powerful tool that enables the identification of variables that significantly influence a process through a matrix of experiments that a software constructs. With the aim of implementing ICTs in the learning—teaching process of polymers in a university group, the polymerization process system of PPMA (polymethylmethacrylate) is studied. The variables that affect the size of the Pearl are: temperature, reaction time and volumen of the polyvinyl alcohol aqueous phase. These variables are optimized through a Box-Behnken experimental design with three factors in three levels, achieving the construction of the response surface to optimize the process, obtaining a tridimensional equation that enables the prediction of the Pearl size through the values of the independent variables. Finally, the student acquires the competency of manipulating the variables that affect the polymerization process to optimize the process. For this reason, Design Expert is a valuable ICT tool in the learning-teaching process of polymerization systems.

Key words: Experimental design, PMMA, ICTs, learning strategies.

1. Introduction

During the learning-teaching process, education requires a series of transformations that enable students competencies development, providing the ablity to make adequate decisions on what to learn and how to apply that knowledge throught their personal and profesional life [1].

The learning and teaching throughout experimental activities that promote logical thinking, in order to promote scientific thinking and students autonomy are essential. The dimensions of scientific thinking are: (1) nature, and (2) science processes, refering the first one to the characteristics of scientific work and the conditions that make science reliable and useful; the second one refers to the processes to generate new knowledge, such as the descriptive and explanatory processes [2].

Research is the strategy for constructing concepts, procedures and attitudes. Through research, the student should be framed into a general intervention classroom model and integrate the contributions of everyday knowledge, knowledge itself and scientific thinking while starting from practical problems [3].

Education in the XXI century is going through a series of transformations inside and outside of the classroom. Inspite of the changes in the educational field, knowing and understanding the learning-teaching process is fundamental to create an effective pedagogical action. To construct significant learning in students, a learning-teaching process needs to be designed in which the student can respond to

Corresponding author: Adolfo Obaya V., Ph.D., research fields: physical chemistry, chemical education.

challenges and act upon them, such as problem based learning [4].

Experimental design is a methodology by which factors (independent variables) that influence a dependent variable are determined. These factors can have different levels (values that the factors have), and the combination between factors and levels determines which variables influence significantly the value of the dependent variable by means of an analysis of variance (ANOVA). This enables a graph construction to optimize the value of the independent variable by manipulating the significant factors. This graph is known as response surface, which is a three dimensional representation of the factors, the levels and the response (value of the dependent variable), achieving the process optimization [5].

A polymer is a high molecular weight molecule which is made up of fundamental repeating units throught the molecule structure. There are several polymerization systems that are divided into two main groups: (1) Homogeneous, in which three types can be found—limited block, continuous block and solution, (2) Heterogeneous, which can be obtained through suspension, emulsion and precipitation [6]. The selected technique depends on the monomer's nature and physical properties. In suspension polymerization the polymer is formed as pearls in the interphase of two inmiscible substances. The variables in which the diameter of polymethylmethacrylate (PMMA) depends on are the mechanical stirring, the reaction's temperature and the quantity of coloidal protector used to avoid the pearls coalescence that are formed throughout the reaction. In the suspension technique (also known as pearl polymerization) the monomer and the trigger are dissolved in an organic solvent. While the reaction occurs, the polymer is formed as droplets which go through different phases—oily, viscous and finally solid. Since the droplets can agglomerate, a protecting agent that covers the surface of the droplet needs to be added so as to avoid agglomeration. Polyvinyl alcohol is widely used as a protective agen in a 1% solution [7]. With this technique, it is difficult to control the size of the polymer pearl.

With the aim of improving the learning-teaching process in the polymer subject, this paper presents the results of a real life problema: Polymerization in pearls of PMMA, where students learn how to use the software Design Expert as an ICT tool to study the process variables in three dimensions, as well as to analyze the variables and interactions among them in a significant way with the use of ANOVA to optimize the process.

2. Methodology

2.1 Population

The strategy was applied within 6 weeks in a Polymer group with 12 students with an average age of 22 (61% men and 38% women) divided in three teams of four people each. The Polymer subject is theoretical and practical (4 hours for lab and 2 hours for theory), with a value of 12 credits, for seventh semester students or above from the Chemical Engineering degree at Facultad de Estudios Superiores Cuautitlán, Universidad Nacional Autónoma de México as a terminal package subject.

Each team made the PMMA polymerization varying the reaction's conditions based on an experiment matrix obtained with Design Expert. The teacher revised the work and provided feedback in a scaffolded way, according to each's team progress and based on the following activities:

- Research about polymerization reactions in updated references
- Investigate different polymerization systems
- Research about the suspension polymerization technique
- Investigate which variables control the size of the pearl in suspension polymerization
- Establish the function of polyvinyl alcohol in PMMA polymerization
- Define what experimental design is

- Which is the objective of doing an experimental design?
- Mention the difference between factors and interactions in an experimental design
- Establish one or several hypothesis and possible results
- Carry out the experiment
- Analyze obtained results
- Make the response surface for the polymerization system
- Obtain the mathematical equation that describes the response surface

2.2 Evaluation

The research process was directed by the teacher, emphasizing the suspension polymerization technique. The research process was directed by the teacher, emphasizing the suspension polymerization technique. Moreover, each experimental session was evaluated through short exams (máximum 20 minutes) to monitor the learning level and its relation with the experimental practice. When all experiments were over, a general exam about polymer concepts and basic definitions of an experimental design was carried out (see appendix).

3. Results and Discussion

The students' literature review was exhaustive, since polymers and polymerization techniques were investigated. The suspension polymerization technique was discussed, as well as the specific system for polymethylmethacrylate.

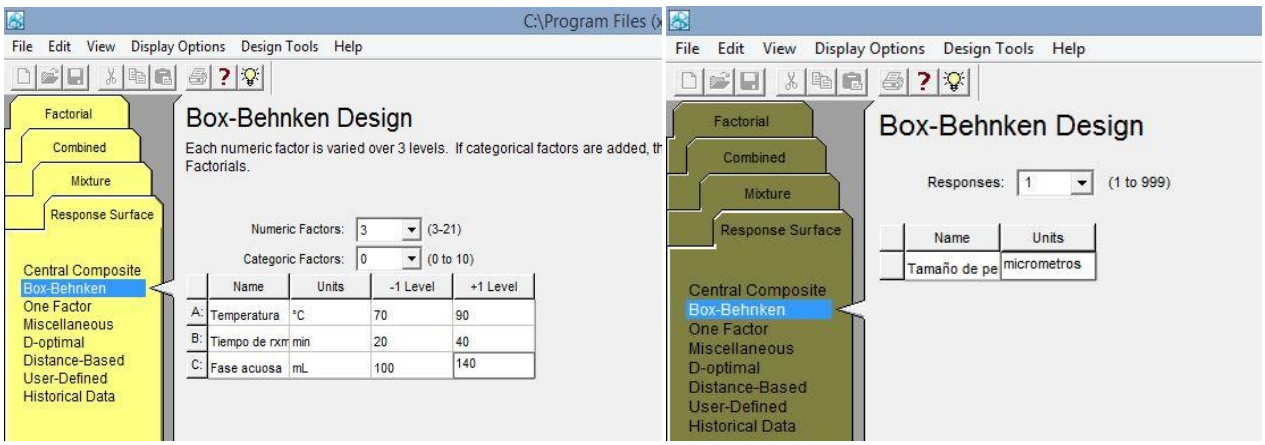
Once students determined the three variables that the PMMA polymerization depends on (temperature, reaction time and polyvinyl alcohol volumen) an experiment matrix according to a Box-Behnken experimental design was made with three repetitions in the center. Based on Table 1, the experimental design for three factors was created:

To make the experiment matrix, the nomenclature (-) for the lowest variable value, (0) for the intermediate value and (+) for the highest was used.

Subsequently, students were taught how to use the software Design Expert as the first step to obtain the experiment matrix. Nomenclature was used in codes, as shown in Fig. 1:

Table 1 Experimental design.

Factor/level	-	0	+
Temperature (℃)	70	80	90
Reaction time (min)	20	30	40
Aqueous phase volume (mL)	100	120	140



(a) (b)

Fig. 1 (a) Factors and levels feeding, (b) the response corresponds to the size of the PMMA Pearl.

Std	Run	Block	Factor 1 A:Temperatura °C	Factor 2 B:Tiempo rxn min	Factor 3 C:Fase acuosa mL	Response 1 Tamaño de per micrómetros
1	11	{ 1 }	-1.000	-1.000	0.000	
2	4	{ 1 }	1.000	-1.000	0.000	
3	1	{ 1 }	-1.000	1.000	0.000	
4	8	{ 1 }	1.000	1.000	0.000	
5	2	{ 1 }	-1.000	0.000	-1.000	
6	15	{ 1 }	1.000	0.000	-1.000	
7	9	{ 1 }	-1.000	0.000	1.000	
8	14	{ 1 }	1.000	0.000	1.000	
9	5	{ 1 }	0.000	-1.000	-1.000	
10	12	{ 1 }	0.000	1.000	-1.000	
11	6	{ 1 }	0.000	-1.000	1.000	
12	3	{ 1 }	0.000	1.000	1.000	
13	13	{ 1 }	0.000	0.000	0.000	
14	10	{ 1 }	0.000	0.000	0.000	
15	7	{ 1 }	0.000	0.000	0.000	

Fig. 2 Experiment matrix calculated by Design Expert.

Once factors and levels were determined, as well as the response, Design Expert constructs the experiment matrix in codified terms as shown in Fig. 2.

For six weeks, students carried out the experiments determined by Design Expert. In each session, questionnaires at the end of the session were used to determine whether students understood the "Why?" and the "What for" of the experimental session, as well as evaluating the learning process. As follows, the evaluation for the first experimental session is shown as a Short Quiz with four questions (Annex. 1):

(1) Write down the definition of a polymer

(2) What is the definition of a monomer?

(3) Draw the molecular structure of the monomers in the methylmethacrylate polymerization

(4) Describe the suspension polymerization technique for PMMA

Based on the answers given by students, it can be determined that the learning process is taking place since the students are able to relate theoretical concepts with the research guided by the teacher.

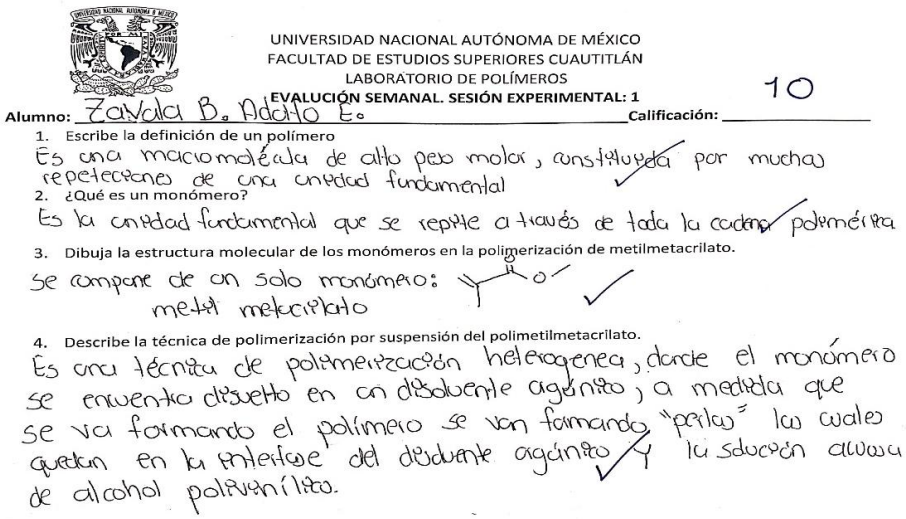
As part of the ICTs implementation process, the explanation on how to use Design Expert continued until experiments concluded and students filled in the experiment matrix with their results (Fig. 2). The aim of letting students make the experimental design was to construct the response surface, and for that it was necessary for students to discriminate the factors and the interactions among factors that alter the size of the PMMA Pearl. With this in mind, the ANOVA chart interpretation was also explained (Fig. 4).

Factors and interactions that have a p (probability) value higher than 0.05 are only taken into account as shown in Fig. 4, since these are the once that significantly influence with a 95% confidence.

Once the experiments were over, students took a final test in regards of acquired knowledge during experimental sessions in order to measure the learning level, as well as concluding over the use of Design Expert Software as an ICT tool for PMMA polymerization (see appendix).

During the learning process, students applied the scientific method and understood the variables that influence the polymerization process, achieving the following through oriented research:

- Adequate literature review—It was an important standpoint to propose the variables that affect the polymerization process through suspension.
- PMMA polymerization—It contributed to handle the equipment and perform adequately in the lab setting for the specific technique.



UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
FACULTAD DE ESTUDIOS SUPERIORES CUAUTITLÁN
LABORATORIO DE POLÍMEROS
EVALUCIÓN SEMANAL. SESIÓN EXPERIMENTAL: 1

Alumno: Zavala B. Adolfo E. Calificación: 10

1. Escribe la definición de un polímero

Es una macromolécula de alto peso molar, constituyeda por muchas repeticiones de una unidad fundamental

2. ¿Qué es un monómero?

Es la unidad fundamental que se repite a través de toda la cadena polimérica

3. Dibuja la estructura molecular de los monómeros en la polimerización de metilmetacrilato.

Se compone de un solo monómero: metil metacrilato

4. Describe la técnica de polimerización por suspensión del polimetilmetacrilato.

Es una técnica de polimerización heterogenea, donde el monómero se encuentra disuelto en un disolvente orgánico, a medida que se vai formando el polímero se van formando "perlas" las cuales quedan en la interfase del disolvente orgánico y la solución acuosa de alcohol polivinílico.

Fig. 3 Answers from a student for the first experimental sesión (Short Quiz).

Transform | Fit Summary | f(x) Model | ANOVA | Diagnostics | Model Graphs

Use your mouse to right click on individual cells for definitions.

Response 1 Bead size

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	8658.23	9	962.03	51.45	0.0002	significant
A-Temperature	*60.50*	*1*	*60.50*	*3.24*	*0.1320*	
B-Reaction Tim	*220.50*	*1*	*220.50*	*11.79*	*0.0186*	
C-Aqueous pha:	*420.50*	*1*	*420.50*	*22.49*	*0.0051*	
AB	*0.000*	*1*	*0.000*	*0.000*	*1.0000*	
AC	*4.00*	*1*	*4.00*	*0.21*	*0.6632*	
BC	*4.00*	*1*	*4.00*	*0.21*	*0.6632*	
A^2	*7067.31*	*1*	*7067.31*	*377.93*	*< 0.0001*	
B^2	*1298.08*	*1*	*1298.08*	*69.42*	*0.0004*	
C^2	*101.77*	*1*	*101.77*	*5.44*	*0.0670*	
Residual	93.50	5	18.70			
Lack of Fit	*85.50*	*3*	*28.50*	*7.12*	*0.1256*	*not significant*
Pure Error	*8.00*	*2*	*4.00*			
Cor Total	8751.73	14				

Fig. 4 Variance analysis for determining variables in significant interactions of the polymerization process.

- Obtained results. It enabled students to formulate new criteria in regards of manipulating studied variables in polymerization through the exper
- Imental sessions and to have an adequate discussion.
- It is important to note that conclusions arose as the outcome of the research process followed by the students by analyzing the ANOVA chart and concluding over the constructed response surface.

In terms of the evaluation results, students

answered the content knowledge related to the subject "Polymers" and basic definitions used in literatura related to experiment design adequately. It is important that based on the question "What have you learned form this PMMA suspension polymerization experience?", focused on the autoevaluation of acquired competencies and abilities were positive. As an example, students provided the following answers after implementing the use of Design Expert:

- We learned how to solve real problems related to polymerization techniques by using a software that oriented us towards making experiments, and not as a traditional lab practice that has to be followed from head to toes.
- With the aim of solving a real problem, we integrated knowledge from various subjects related to Chemical Engineering.
- We were stimulated to work in the lab based on our reflective abilities and initiative.
- We could understand statistics concepts, as ANOVA, and apply them to a real problem that could happen to us in the industrial environment.
- We learned how to optimize variables thanks to the use of Design Expert.

Answers indicate that students consider they have acquired the needed competencies and abilites that will be useful in profesional development, such as the use of software that will enable them to solve problems in an efficient and fast way.

The final exam (Annex 2) consisted of 10 questions, divided in three sections according to the learning level [8]. The percentage of correct answers is shown in Fig. 5.

Finally, a research report presented by one of the teams is shown as an example, that can be used as a basis and possible orientation for those who would like to implement this approach.

4. Research Report (Made by Students)

4.1 Introduction

Polymers are high molar mass molecules (macromolecules) which are constituted by fundamental repeating units known as monomers. Nowadays, polymers are widely used in all economic sectors (used for packaging and distribution of cosmetic products, food, detergents, etc.) as well as creating materials used in construction, textiles, shoes, etc. Hence, studying these polymers is essential for chemical engineers, who can run into them while working in the industry.

Polymerization reactions can be classified in the following way:

(1) Free radicals: In this type of reactions, an initiator (usually an organic peroxide or azoic compounds) is used to easily produce free radicals. Once the free radical is form, this reacts with the monomer achieving homolytical ruptures in its bond. With this, the monomer is activated and in turn, the monomer reacts with other molecules "n" times. Each time, the chain increases its size, and therefore the molar mass, obtaining the polymer.

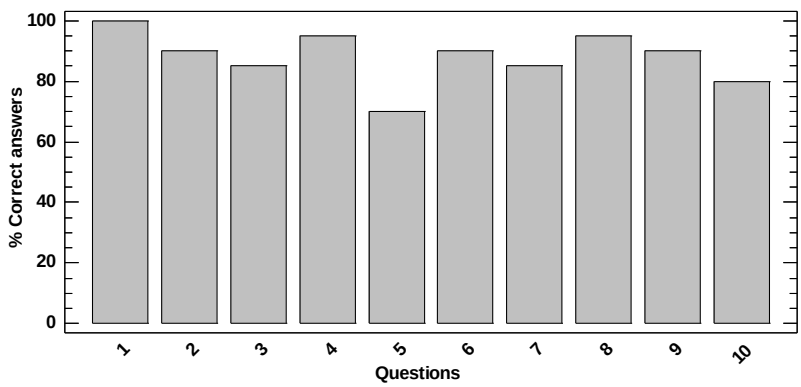


Fig. 5 Percentage of correct answers in the final evaluation.

Table 2 Polymerization system types.

Relationship between the phase monomer-polymer	Monomer position	
	Continuous	Disperse
Homogeneous (same phase)	In solution in solid state, in block	In suspension
Heterogeneous (different phases)	In block with polymer precipitation	In emulsion In suspension with polymer precipitation

Table 3 Polymerization systems comparison.

Type	Advantages	Inconveniences
Homogeneous		
In limited block	Simple equipment	Dissolution and further precipitation can be needed for purification or manufacturing It may be necessary to reduce the size to a usable particle Difficult thermal control Wide distribution of molecular weights
In continuous block	Easier thermal control Narrower distribution of molecular weights	Reagent recycling needed Dissolution and further precipitation might be needed for purification or manufacturing More complicated equipment is required It may be necessary to reduce the size to a usable particle
In dissolution	Easy stirring Allows the formation of longer polymeric chains Easy thermal control	Stirring is necessary Solvent elimination and recycling is needed Polymer recovery is needed Nocive chain transfer with solvent might occur (reaction with the solvent)
Heterogeneous		
In emulsion	Easy thermal control Easy stirring Produced latex can be used directly Fast reactions are possible Molecular weight can be controled Small particle size are possible Used for sticky, bland and solid products	Polymer may require additional cleaning and purifications Precipitation can limit the weight Incrusted coagulants, emulsifiers, surfactants, etc. are hard to eliminate Fast stirring is usually needed
Precipitation	Molecular weight and molecular weight distribution can be controlled by managing the polymerization environment	May require dissolving and reprecipitating the product to eliminate unwanted substances. Precipitation can limit the molar weight, not allowing the formation of very high molecular weight products.
In suspension	Easy stirring Higher purity product compared to the one obtained by emulsion	Sensitive to stirring Particle size is hard to control

(2) Condensation: These reactions take place when the monomers have functional groups that react with each other, generally through sterification reaction, where there is always the loss of a low molar mass molecule in each condensation.

Classifications can also be based on the polymerization technique:

Many monomers, as styrene, acrylonitrile and vinyl chloride are toxic and yield highly exothermal reactions. Therefore, safety precautions are needed to minimize contact with the compounds and to control the reaction's temperature. The main polymerization methods are: block, emulsion and dissolution. Each of these methods provides both advantages and disadvantages.

The polymerization system studied at the lab is polymethylmethacrylate (PMMA), which is carried out through the suspension polymerization technique. There are certain characteristics of this technique that are noteworthy.

4.2 Suspension Polymerization

If the monomer is not solluble in water, mass polymerization in suspended drops can be carried out.

The aqueous phase becomes the means for the heat transference. Since the phase is continuous, viscosity slightly varies with the conversion, in such a way that the heat transfers to the recipient's wall in which polymerization taking place can be efficient. The behavior within the drops is very similar to mass polymerization. Since the drops have only 10 to 100 μm in diameter, higher speed reactions can be tolerated without the monomer boiling. To avoid the coalescence while they are changing from liquid to solid state going through an adhesive phase, it is necessary to use a protective colloid (suspension agent) as well as careful stirring. Polyvynil alcohol dissolved in the aqueous phase is a typical suspension agent. Electrostatic charges are introduced in the suspended monomer—polymer particles. These charges do not avoid particles going up in case of stirring stops. The size of the particle and the size distribution are affected by the suspension agent and the stirring speed. Fondy, Bates and Fenic [9] found that for a diameter particle range of 10 to 1,000 μm, diameter varies inversely proportionally with the speed of the driving extreme speed elevated to the potence 1.8 for a diversity in the driving designs.

The term suspension polymerization refers to the polymerization in an aqueous system with a monomer in a disperse phase, that produces a solid polymer in a disperse phase. In a typical suspension polymerization, the initiator is dissolved in the monomer phase. The monomer dispersion in drops is kept by a combination of stirring and stabilizers used in water. Among these, solluble organic and inorganic materials that intervene in the polymer drops aglommeration that may exist by mechanical stirring are included. The tendency to aglommerate can be critical when polymerization has advanced upto the point in which the polymer pearls are sticky. When the reaction is finished, the polymer is freed from the stabilizer by washing and drying. For certain applications, pearls can be used directly. In other cases, compacting is necessary. This method is used commercially for vitreous, hard polymers such as polystyrene, PMMA, vynilidene polychloride and polyacrylonitryle.

4.3 Objectives

(1) To perform the PMMA polymerization by using the suspension polymerization technique

(2) To determine the variables that influence the PMMA particle size

(2) To create a response surface by designing a Box-Behnken experiment, obtaining the mathematical model to predict the size of the Pearl

4.4 Method

Table 4 shows the materials, reagent and equipment used based on the FES Cuautitlán polymer lab infrastructure.

4.5 Experimental Methodology

4.5.1 Experiment Matrix Obtention through Design Expert

In order to obtain the experiment matrix, variables

Table 4 Material, equipment and reagents used for PMMA Polymerization.

Materials	Reagents	Equipment
2 Florence flasks 250 mL 2 Erlenmeyer Flasks 50 mL 1 graduated cylinder 250 mL 1 graduated cylinder 50 mL 1 pipeta graduada 5 mL 1 graduated pipette 1 mL 1 watch glass 1 magnetic stirrer hot plate 1 magnetic stirrer bar 1 mercury thermometer 0-100 ℃ Glass wool Filter paper (small pores)	Polyvynil alcohol Methylmethacrylate Divynilbenzene Ethylvynilbenzene Isooctane (or n-octane) Benzoyl peroxide Dimethyl p-toluidine	OAHUS 1121 Analytical scale Tekton 7169 dial indicator

Table 5 Factors and levels for the experimental design.

Factor/level	-	0	+
Temperature (°C)	70	80	90
Reaction Time (min)	20	30	40
Aqueous phase volume (mL)	100	120	140

Table 6 Experiment matrix for PMMA polymerization.

Experiment	Factor 1 A: Temperature (°C)	Factor 2 B: Reaction time (min)	Factor 3 C: Aqueous phase (mL)
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

that affect the size of the PMMA Pearl were discussed in class, determining that these are: (1) System's temperature (2) Reaction time and (3) Polyvynil alcohol aqueous phase volume. Since it is a three-factor experiment, levels were determined according to Table 5.

With these values, the following matrix was created (Table 6).

4.5.2 PMMA Polymerization

Based on the experiment matrix, 35 mL of methyl methacrylate (monomer) was placed in the Florence flask, adding 1.8 g of benzoyl peroxide as the initiator and quantities of polyvynil alcohol, temperature and reaction times varied. Each polymerization system was carried out using slow magnetic stirring.

4.6 Results and Analysys

Once experiments concluded, Table 7 was filled in according to the Pearl diameter obtained for each system.

Next, the ANOVA chart is presented in which variables that have a *p* value (probability) higher than 0.05 are the ones that significantly influence the response—the size of the Pearl—with a significance level of 5%.

Once the influential variables are obtained, the Model graphs are selected to construct the response Surface with the software (Fig. 7).

Then, the software shows the Surface response through 3D surface (Fig. 8)

The software can also show the Surface by combining the independent variables as shown in Fig. 9:

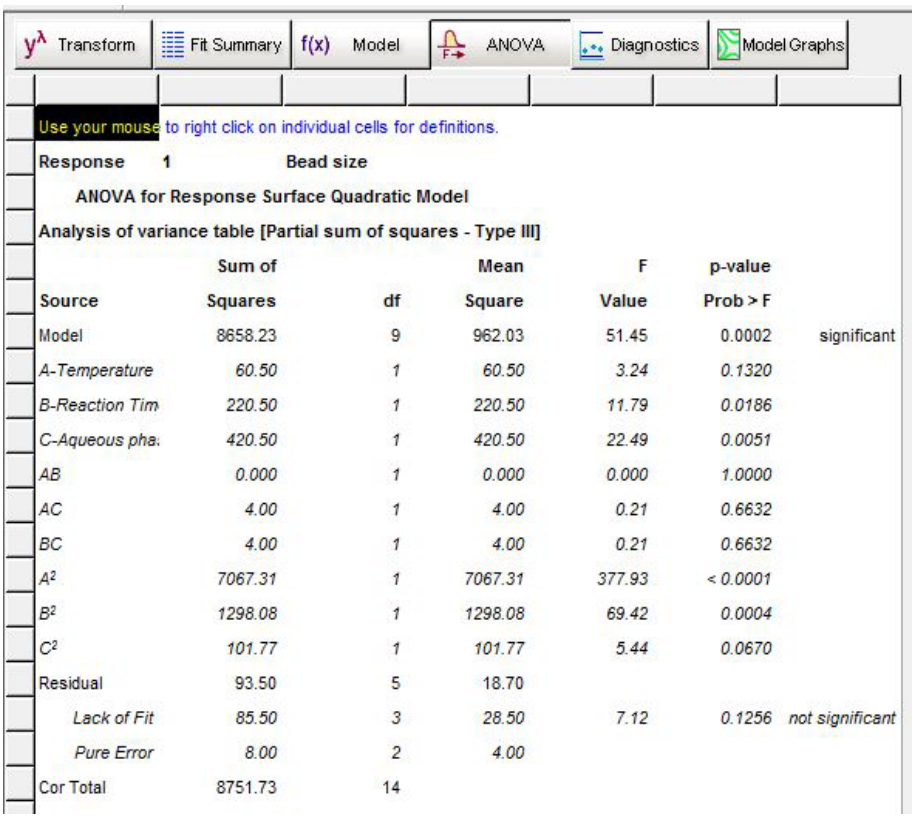
The equation for the polymerization system was also obtained:

$$Size\ of\ the\ pearl = 55.92 + 0.50A + 5B + 3.75C + 0.25AB - 29.87A^2 - 16.87B^2 - 3.75A^2B + 0.75AB^2$$

Being factors A, B and C temperature, reaction time and aqueous phase volume respectively, the descriptive equation shows that the reaction time is the factor that affects the most since it has the highest coefficient value. To validate the equation, residuals graph is

Table 7 Pearl diameter obtained for each system.

Experiment	Factor 1 A: Temperature (°C)	Factor 2 B: Reaction time (min)	Factor 3 C: Aqueous phase (mL)	Response: Pearl diameter (micrometers)
1	-1	-1	0	10
2	1	-1	0	15
3	-1	1	0	20
4	1	1	0	25
5	-1	0	-1	25
6	1	0	-1	29
7	-1	0	1	31
8	1	0	1	39
9	0	-1	-1	41
10	0	1	-1	50
11	0	-1	1	60
12	0	1	1	73
13	0	0	0	80
14	0	0	0	78
15	0	0	0	82



Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	8658.23	9	962.03	51.45	0.0002	significant
A-Temperature	60.50	1	60.50	3.24	0.1320	
B-Reaction Tim	220.50	1	220.50	11.79	0.0186	
C-Aqueous pha:	420.50	1	420.50	22.49	0.0051	
AB	0.000	1	0.000	0.000	1.0000	
AC	4.00	1	4.00	0.21	0.6632	
BC	4.00	1	4.00	0.21	0.6632	
A^2	7067.31	1	7067.31	377.93	< 0.0001	
B^2	1298.08	1	1298.08	69.42	0.0004	
C^2	101.77	1	101.77	5.44	0.0670	
Residual	93.50	5	18.70			
Lack of Fit	85.50	3	28.50	7.12	0.1256	not significant
Pure Error	8.00	2	4.00			
Cor Total	8751.73	14				

Fig. 6 ANOVA chart for the PMMA polymerization variables.

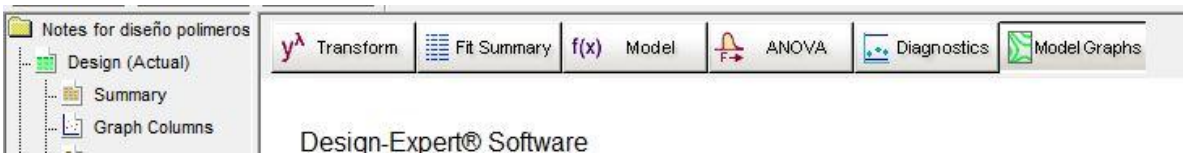


Fig. 7 Tab to construct the surface response.

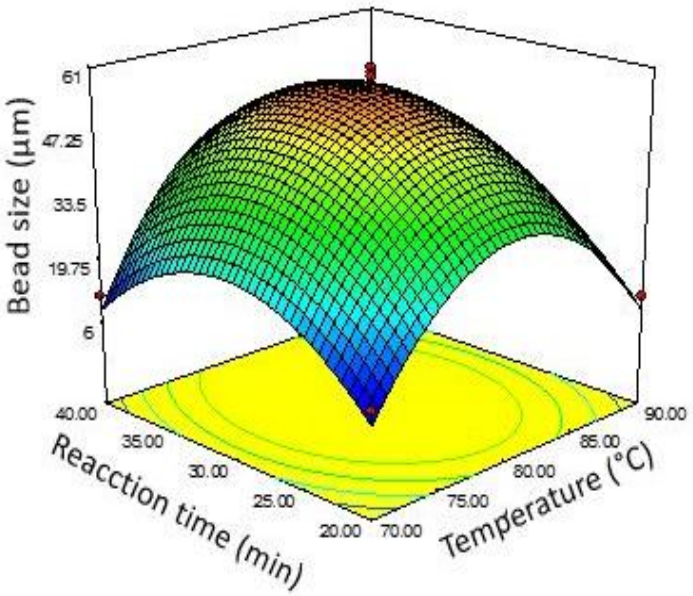


Fig. 8 Surface response for PMMA polymerization, with reaction time and temperature as independent variables.

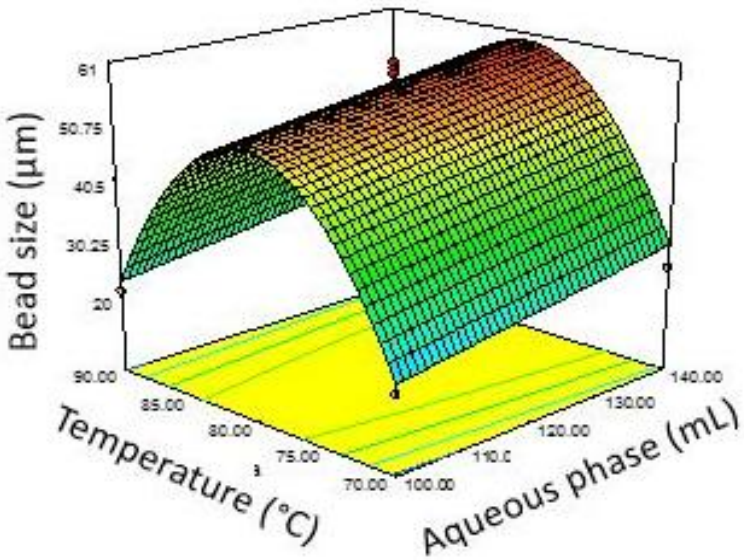


Fig. 9 Surface response for PMMA polymerization with temperature and aqueous phase volumen as independent variables.

shown (such as in homoscedastics) infering that the equation is valid and correctly describes the variable correlation.

4.7 Conclusions from the Students Report

After experimentally performing the polymerization by using the suspension technique, it can be concluded that the size of the Pearl is primarily affected by reaction time over the volumen of polyvynil alcohol in the aqueous phase and the temperature. By using Design Expert, the Surface response was created, optimizing the size of the pearl, being the optimal conditions 80 ℃, 30 minutes of reaction time and 120 mL of the aqueous phase to obtain a 60 µm pearl. Factors and interactions that affect the polymerization process were also discriminated by using the variance analysis (ANOVA) as well as the mathematical model, through the residuals graph. Since the latter is homoscedastic, the mathematical model is valid and adjusts to the experimental data.

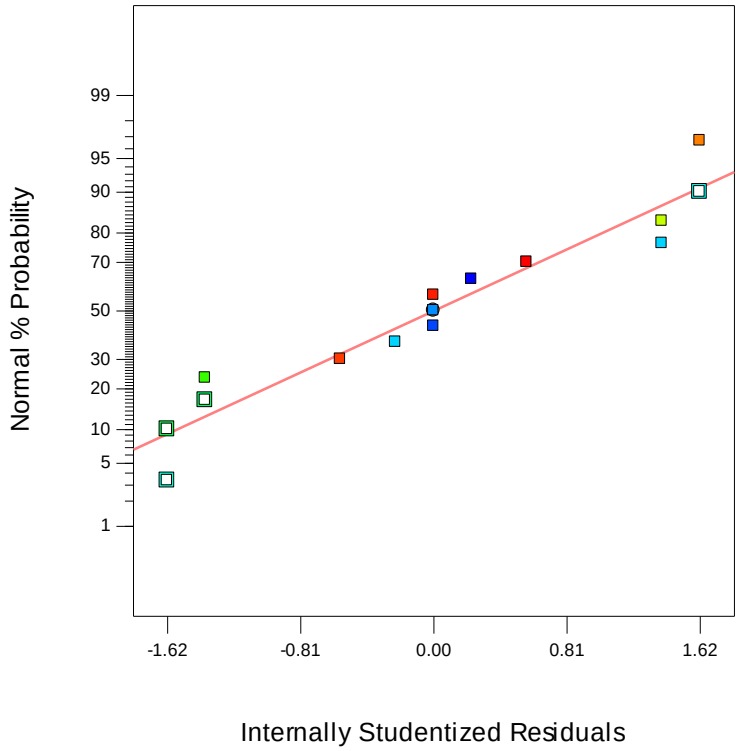


Fig. 10 Residuals graph for the polymerization process mathematical equation.

5. Conclusions

With the aim of improving the learning and teaching [10] of polymers through implementing ICTs, the students enrolled in the subject performed a PMMA suspension polymerization following an experiment matrix obtained with Design Expert. Afterwards, they treated the experimental data obtained in the experimental sessions and constructed the surface response by using a variance analysis (ANOVA). This led to the mathematical model obtained by the analysis of residuals graph.

Using ICTs as a tool for the learning and teaching process becomes an important didactic strategy to motivate students through the use of software that facilitates learning and fosters scientific thinking based on experimental results. This in turn, allows students to aquire the competence for problem solving related to polymerization systems and techniques.

By using ICTs teachers can adjust knowledge construction, recognize creativity, autonomy and communication in students development by organizing contenta round problema solving nd fostering the professionalism of study plans, such as in the polymer laboratory.

This proposal is important for learning the chemistry of polymers since it enabled the students to use and unify concepts, allowing them to understand variables that affect polymerization, especially PMMA.

Developing these types of strategies promotes the study of new topics, in an era where polymers are found everywhere, favoring the scientific thinking through the use of ICTs as a didactic principle.

For chemistry teachers this proposal becomes useful since the performed stages are described and can be replicated in experimental labs, fostering research in polymerical systems with diverse applications (industrial, commercial and domestic).

References

[1] Olivares, S., and Heredia, Y. 2012. "Desarrollo del pensamiento crítico en ambientes de aprendizaje basado en competencias en estudiantes de educación superior."

Revista Mexicana de Investigación Educativa 27 (54): 759-78.

[2] Olguín, M. A., and Obaya, A. 2016. "La relación estructura propiedad a través del desarrollo de habilidades de pensamiento. Eutopía." *Didáctica de las Ciencias Experimentales* 9 (25): 93-100.

[3] Obaya, A., and Delgadillo, G. 2003. "La investigación como principio didáctico en el laboratorio de Química Industrial." *Educación Química* 24 (1): 10-6.

[4] Andrews, S. 2003. "Just Like Instant Noodles: L2 Teachers and Their Beliefs about Grammar Pedagogy." *Teachers and Thinking: Theory and Practice* 9: 351-70.

[5] Miller, J. 2002. *Estadística y quimiometría para química analítica*. Pearson, España.

[6] Billmeyer, F. 2004. *Ciencia de los polímeros*. Reverté, España.

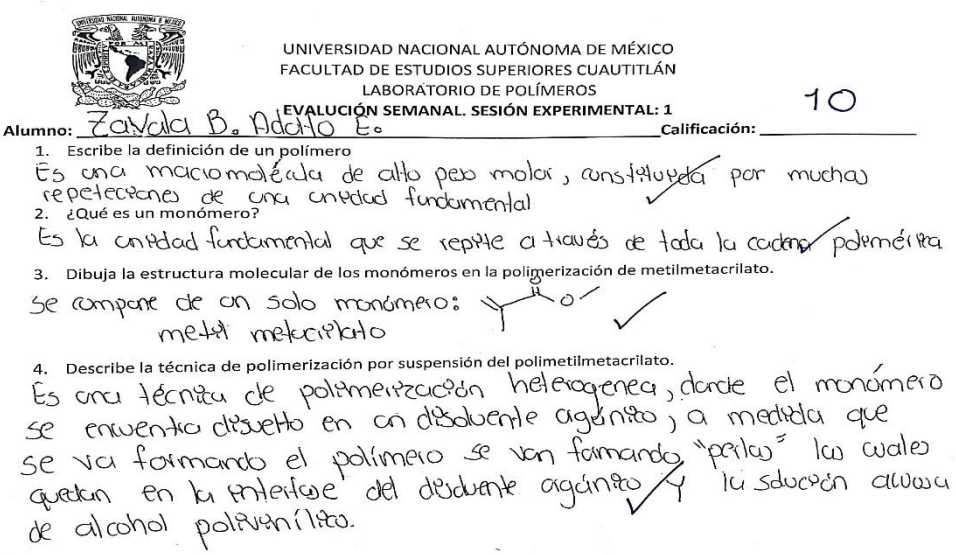
[7] Seymour, R. B., and Mark, H. F. 1987. *Applications of Polymers*. New York and London: Plenum Press.

[8] Marzano, R. J., Pickering, D. J., and Pollock, J. E. 2001. *Classroom Instruction that Works: Research-Based Strategies for Increasing Student Achievement.* Alexandria, VA: Association of Supervision and Curriculum Development.

[9] Fondy, P. L., Bates, R. L., and Fenic, J. G. 1966. "Impeller Characteristicsand Power." In *Mixing: Theory and Practice,* Volume I, edited by V. M. Uhl and J. B. Gray. New York: Academic Press.

[10] Obaya, A., Vargas, Y-M., Montaño, C., and Giammatteo, L. 2019. "The Role of Educational Research in Teaching Chemistry." *International Journal of Development Research* 9 (1): 25253-7.

Annex 1: Short Quiz



UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
FACULTAD DE ESTUDIOS SUPERIORES CUAUTITLÁN
LABORATORIO DE POLÍMEROS
EVALUACIÓN SEMANAL. SESIÓN EXPERIMENTAL: 1

Alumno: Zavala B. Adalto E. Calificación: 10

1. Escribe la definición de un polímero

Es una macromolécula de alto peso molar, constituyeda por muchas repeteciones de una unidad fundamental

2. ¿Qué es un monómero?

Es la unidad fundamental que se repite a través de toda la cadena polimérica

3. Dibuja la estructura molecular de los monómeros en la polimerización de metilmetacrilato.

Se compone de un solo monómero: metil metacrilato

4. Describe la técnica de polimerización por suspensión del polimetilmetacrilato.

Es una técnica de polimerización heterogenea, donde el monómero se encuentra disuelto en un disolvente orgánico, a medida que se va formando el polímero se van formando "perlas" las cuales quedan en la interfase del disolvente orgánico y la solución acuosa de alcohol polivinílico.

Annex 2: Final evaluation (applied to the group)

(1) Place the correct letter inside the parenthesis

1. A polymer is a macromolecule ( )

constituted by fundamental and repetitive units known as monomers

simple, with low molecular weight

that presents ionic bonds.

that can´t be broken into lower molecular weight molecules

2. In free radical polymerization reactions ( )

activation energy is high

homolytic ruptures in monomers occur, incrementing the size of the chain

fragile polymers are formed

water vapor is a subproduct

3. These are initiator examples for free radical polymerization reactions ( )

sodium nitrate and ammonium chloride y cloruro de amonio.

sodium sulphate and chlorhydric acid

benzoyl peroxide and azobenzene

hydrogen peroxyde and benzaldehyde

4. Homogeneous polymerization techniques ( )

Limited block and emulsion

Continuous block and suspension

Precipitation and emulsion

Dissolution and continuous block

5. Polymerization technique in which polymer pearls are formed in an organic and an aqueous phase. ( )

Suspension.

Emulsion.

Precipitation.

Dissolution.

(2) Answer the following questions correctly.

Which is the function of the polyvynil alcohol in the suspension polymerization?

What does the term “coalescence” mean in suspension polymerization?

(3) Relate the following columns correctly.

Factor	3D graph that shows the optimal conditions for a process
Level	Values that independent variables can take
Surface response	Independent variables a process may depend on that can be manipulated