Chemical Engineering Research Bulletin 21(2019) 46-57 Available online at http://banglajol.info/index.php/CERB

OPTIMIZATION OF ENERGY CONSUMPTION IN ACETIC ACID AND N-BUTANOL ESTERIFICATION REACTION WITH SIMULTANEOUS WATER REMOVAL USING NOVEL MICROCONTROLLER BASED AUTOMATED REACTOR

Amol A. Bhusari[1], Bidyut Mazumdar[2] and Ajit P. Rathod[3]*

[1,2]Department of Chemical Engineering, National Institute of Technology, Raipur, India
[3]Department of Chemical Engineering, Visvesvaraya National Institute of Technology Nagpur, India

Received 08 July 2019

Abstract: This paper focuses on the optimization of energy consumption in esterification of acetic acid wherein the water removal is achieved by using silica gel desiccant in a microcontroller based automated reactor. Esterification reactions are endothermic hence, one can get more product, by increasing the temperature, thus disturbing the equilibrium. Heat of reaction (*Hr*) was estimated by using the heat capacity data and constants (C). Energy analysis and modelling was developed for the enhancement of process which is the key component of the systems. The mathematical model is validated by experimental results. In this paper, effect of parameters like desiccant weight, regeneration temperature and molar ratio on energy consumption are studied. Trends of energy effectiveness of several parameters are presented in the various regeneration temperatures and molar ratio and desiccant weight which confirmed the linear relationship with hot air flowrate. Decrease of 33% in power consumption was observed by decreasing the hot air flowrate by 10%.This is the conformity of validation of affinity law. The newly invented model was optimized for variables, hot air temperature, molar ratio and silica gel weight. The minimum energy consumption at 1 desirability was reported by software in the given range of parameters. When the hot air temperature, molar ratio and silica gel weight were 67.67^{0}C, 3 and 34.32 gm, then the minimum value of energy consumption was 29.59 Watt.

Keywords: *Acetic acid, RSM, MBAR, Energy consumption, Silica gel*

DOI: https://doi.org/10.3329/cerb.v21i1.47371

1. Introduction

Conservation of energy is always a top priority for any industrial organization. Despiteously, since last decade, energy efficiency in Indian industry has increased consistently. In the major energy intensive industrial sectors, like cement, steel, aluminium, fertilizers, etc., average specific energy consumption has been reducing due to new capacity addition with state-of-the-art technology. Still these sectors being major energy intensive have been notified by Bureau of Energy Efficiency, India, for consuming high energy. Table 1 Depicts India's minimum annual energy consumption for the designated consumer (DC)[1]. Various models have been applied for estimating efficient energy use in cement industry. The outcome of model after analysis concluded that there is a scope for improvement in energy efficiency and thereby saving energy[2]. The textile industries consumes huge amount of energy both in the form of electrical and thermal for processing.

The cost of energy varies between 15 to 20% of total manufacturing cost[3]. In many chemical processes like manufacturing of bioethanol, the large demand for energy refrain from achieving the purity of product. However, this issue is resolved by optimizing the process parameter using statistical method indistillation[4]. Implementation of statistical process control and design of experiments not only helps to achieve the target, but also save time and money during product and process development. The outcome of this practice helps in scaling up from pilot studies along with an improved management of manufacturing process[5]. Response Surface Methodology (RSM) is

---

*Corresponding author Email: ajitprathod@gmail.com

an important engineering tool applied for process development through experimental design. One of its application has been thrust into limelight when optimization of dwell time (time after which heat intensity starts to heat work piece in seconds) and gap between the work piece proved its effect on energy intensity in foundry[6].

Table 1: Minimum Annual Energy Consumption for the Designated Consumer (DC) in India

Sector	**Minimum annual energy consumption for the DC (Tonnes of oil equivalent-toe)**	**No. of DCs**
Cement	30,000	85
Iron and steel	30,000	67
Aluminium	7,500	10
Fertilizer	30,000	29
Pulp and paper	30,000	31
Textiles	3,000	90
Chlor-alkali	12,000	22
Thermal power plants	30,000	144

Another application of RSM using a Central Composite Design (CCD) in microwave sterilization offered high efficiency than conventional steam sterilization for lipase inactivation owing to very low p-values of interaction parameter preferably electrical utility like power[7]. However, when CCD was applied in membrane distillation process using direct contact (DCMD) it was found helpful not only to optimize independent process variables[8], but also in analyzing the thermal energy savings opportunities. RSM has been deployed in various fields, adsorption[9,10], drying process[11], transesterification[12].

In esterification, the process parameter like molar ratio, reaction temperature, and catalyst loading has been successfully optimized by various researchers by using Box-Behnken factorial design. Thus they concluded that the catalyst they used is an efficient, time saving with increased conversion for product formation[13,14]. However, in some esterification processes it is observed that, the yield of product accompanied with water removal by adsorption depends on the type of alcohol, and the energy consumption is a function of boiling point of the particular alcohol. Normally the energy consumption is reduced for the alcohol having high carbon chain. This is considered as disadvantage of process for limitation in alcohol selection for favoring energy conservation[15]. Researcher reported that high mass transfer resistance in some esterification processes is the possible reason that makes them energy inefficient. However, hydrodynamic cavitation in such process reduces mass transfer resistance and thereby making the process more efficient[16].

Recently some researcher reported that bio-based desiccants adsorb water up to 4.5% by weight from alcohol water mixture. They concluded that, uptake capacity of water in vapor form is higher than that of liquid for effective adsorption[17,18]. In this present work the optimization of various parameters like silica gel weight, Hot air temperature and molar ratio for response of energy consumption in a microcontroller based embedded system for esterification of acetic acid and n-butanol is studied. As the conversion of acid progresses the amount of water generation also increases[19]. As the water is having the highest heat capacity, it requires high amount of heat to raise its temperature[20].

2. Experimental Section

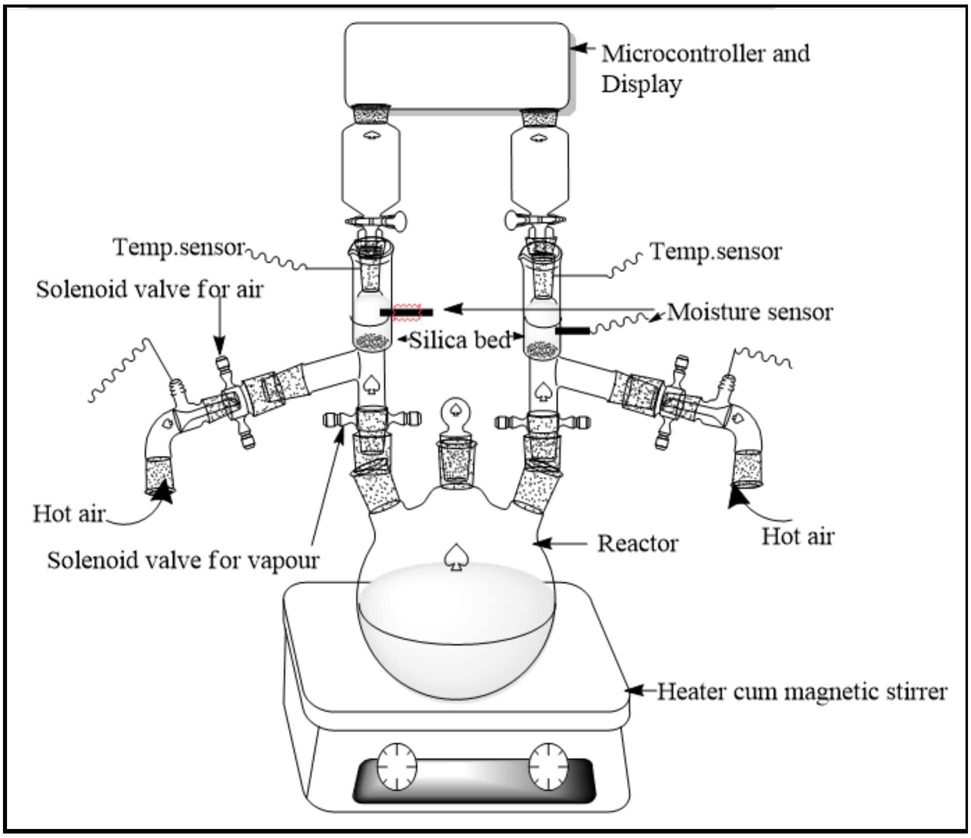

Figure 1: Schematic set up of MBAR

2.1 Materials

The chemicals such as n-butyl alcohol (purity > 99%), acetic acid (purity > 99%), HCl, H_2SO_4, used in this study were purchased from Merck. Karl Fischer reagent and methanol were purchased from Rankem Chem. Ltd. (Mumbai, India) and n-hexane (GC grade) was obtained from Sigma-Aldrich. All chemicals used were of analytical reagent grade and further purification was not needed. The heterogeneous catalyst used in the study was prepared from cajanus cajan husk. De-ionized water followed by double distillation was used in the study. Intermediate density silica gel was used for absorbing moisture in the reaction.

2.2 Development of automated embedded-assisted system for esterification reaction

Figure 1 shows the schematic set-up of microcontroller based automated reactor (MBAR) consisting of two fixed beds of silica gel, one adsorbing and one regenerating; later those functions are reversed. Esterification reaction between acetic acid and n butanol was conducted in a 250 ml flask. The temperature of reactants was raised using heater cum magnetic stirrer. The water of esterification was adsorbed in silica gel desiccant of appropriate weight. The process of esterification controlled, programmed, developed and automated using microcontroller based embedded system, accompanied by several other electronic components like Arduino board (ATmega328) and sensors for measuring temperature (LM35), moisture (FC28), solenoid valves, relays and LCD display. The sensors are used to monitor and provide feedback for automation whereas relays are used to interface and operate solenoid valves. Temperature and moisture level are displayed on the 16x2 alphanumeric LCD display. Hot air blowers were used to dry and regenerate the silica beds.

2.3 Procedure

Butanol to acetic acid in2:1 ratio in the presence of heterogeneous sulfonated carbon catalyst was charged to MBAR. The reaction temperature and stirring speed was set at 90^0C and 400 RPM respectively. The device and process parameter are controlled by a programmed electronic system having microcontroller, sensors, relays and LCD display. On heating, evaporation starts, and the vapor mixture are directed towards the silica bed (SB1) by opening solenoid valve (SV2). The moisture content of silica bed is sensed by moisture sensor M2 and the corresponding analogue signal is generated and displayed on LCD screen. Due to absorption of moisture the silica bed is saturated, and the vapors are directed towards second silica bed. Meanwhile the saturated bed is regenerated by supplying hot air. The temperature of hot air was varied from 60^0C to 70^0C; and the flow was measured by vane type anemometer (0 – 45 m /sec.) the reaction mixture was titrated with 2 N NaOH to determine the conversion. The electrical parameters were measured at 5 s with the help of clamp-on power analyzer (0 - 1200 kW, 0 - 2000 A, Current, AC / DC.

2.4 Heat of reaction

Esterification reactions proceed by absorbing energy to get complete and hence fall into category of endothermic reactions. When such reactions absorb energy, positive heat flow results in increase in the enthalpy. The quantity of heat needed to raise the temperature depends on the heat capacity of component[21]. Moreover, as the conversion increases, the yield increases so the specific energy consumption (SEC) which is the ratio of energy consumed per unit weight of production is major role to play. The esterification reaction for 2:1 alcohol to acid molar ratio is balanced as eq.1

$$aCH_3COOH + bC_4H_9OH \rightarrow cCH_3COOC_4H_9 + dH_2O \qquad (1)$$

The heat of reaction (ΔHr) at 90^0C is evaluated as depicted by equation 2. Where, Δ represents the algebraic summation of constants of the heat capacity.

$$\Delta \mathrm{Hr} = \Delta \mathrm{H}_0 + (\Delta \mathrm{a} \times \mathrm{T_r}) + \left(\Delta \mathrm{b} \times \frac{(\mathrm{Tr})^2}{2}\right) + \left(\Delta \mathrm{c} \times \frac{(\mathrm{Tr})^3}{3}\right) + \left(\Delta \mathrm{d} \times \frac{(\mathrm{Tr})^4}{4}\right) \qquad (2)$$

$$\Delta a = \left(\left(n_{ba} \times C1_{ba}\right) + \left(n_w \times C1_w\right)\right) - \left(\left(n_{aa} \times C1_{aa}\right) + \left(n_b \times C1_b\right)\right)$$
$$\Delta b = \left(\left(n_{ba} \times C2_{ba}\right) + \left(n_w \times C2_w\right)\right) - \left(\left(n_{aa} \times C2_{aa}\right) + \left(n_b \times C2_b\right)\right)$$
$$\Delta c = \left(\left(n_{ba} \times C3_{ba}\right) + \left(n_w \times C3_w\right)\right) - \left(\left(n_{aa} \times C3_{aa}\right) + \left(n_b \times C3_b\right)\right)$$
$$\Delta d = \left(\left(n_{ba} \times C4_{ba}\right) + \left(n_w \times C4_w\right)\right) - \left(\left(n_{aa} \times C4_{aa}\right) + \left(n_b \times C4_b\right)\right)$$

Thermodynamic data to estimate the heat of reaction at 90^0C is given in table 2.

$$\text{Energy consumption (Watt)} = \mathrm{Hr} \times \left[\frac{\mathrm{n_{aaf}}}{1000}\right] \times (\mathrm{T_r}) \times \frac{1}{(\mathrm{t} \times 60)} \qquad (3)$$

Table 2: Data of Thermodynamic Constants

Components	***C1***	***C2***	***C3***	***C4***	***C5***
Acetic Acid	*1.40×10^5*	*-3.21×10^2*	*8.99×10^{-1}*	*0*	*0*
Butanol	*1.91×10^5*	*-7.30×10^2*	*2.30*	*0*	*0*
Butyl Acetate	*1.17×10^5*	*3.52×10^2*	*0*	*0*	*0*
Water	*2.76×10^5*	*-2.09×10^2*	*8.13*	*-1.41×10^{-2}*	*9.37×10^6*

Heat Capacity Constants

Butyl Acetate	*3.74×10^4*	*1.12×10^2*	*0*	*0*	*0*
Water	*8.81×10^4*	*-6.66×10^2*	*2.59*	*-4.50×10^{-3}*	*2.99×10^{-6}*
Total	*1.26×10^5*	*-5.54×10^2*	*2.59*	*-4.50×10^{-3}*	*2.99×10^{-6}*

3. Analysis

The reproducibility of the result was ensured by repeating the experiments three times. The concentration of unreacted acetic acid was determined by titrating with 0.1 N NaOH. Phenolphthalein was used as an indicator. The water content of the medium was determined by using microprocessor based Karl Fischer titrator (Optics Technology, India). The power consumption was measured by using power analyzer. While the hot air flow was measured by using vane type anemometer. The standardization of NaOH was done with 0.1 N HCl. The amount of water accumulated in the bed at saturated level with respect to time in terms of moisture (M%) developed using MBAR is depicted by equation 4.

$$\mathrm{M\%} = \frac{10000\,\mathrm{Q_W}}{\left((\mathrm{W_{sat}} + \mathrm{Q_W})\left(100 - 89.31\exp\left(\frac{\mathrm{Q_W}}{-1.78}\right) + 9.02\right)\right)} \quad (4)$$

4. Result and Discussion

4.1 Effect of conversion rate on energy consumption

As the esterification proceeds, the content of water in the system increases. This results in hindering the forward shift. Moreover, the presence of water causes deactivation of catalyst reaching to rate determining step quickly[19]. However simultaneous removal of water from the reaction medium enhances the yield of product. Figure 2a, 2b and 2c depicts that the water content in the medium increases with the conversion of acetic acid. As high-water content demands for high heat energy due to high heat capacity of water the energy consumption in each case increases.

4.2 Effect of air flow rate on power consumption

The hot air was used to regenerate the saturated silica gel. The air flow rate Q_a was measured by vane type anemometer. The electrical parameters like current, voltage drawn by blower were measured to calculate the power consumption. Good exponential relationship in power consumption was observed. It was also noted that decrease in flow by 10% decreases the power consumption by 33%. This is the validation of affinity law (Eq^n 5). From figure 3a, 3b and 3c, it was observed that the airflow requirement reduces when the inlet temperature of air is increased.

$$\mathrm{Q_a} \alpha \mathrm{P}^3 \quad (5)$$

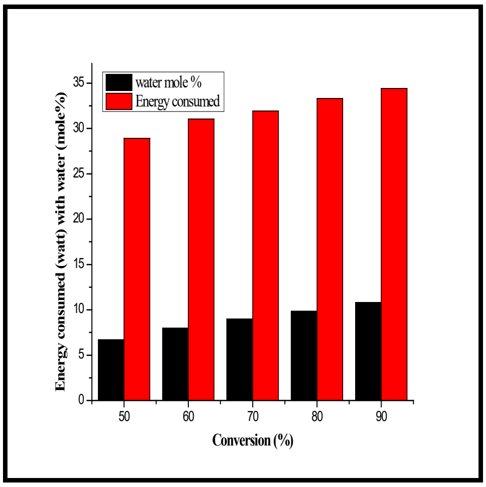

Figure 2a: Effect of conversion on water content and energy consumption at 2:1 ratio

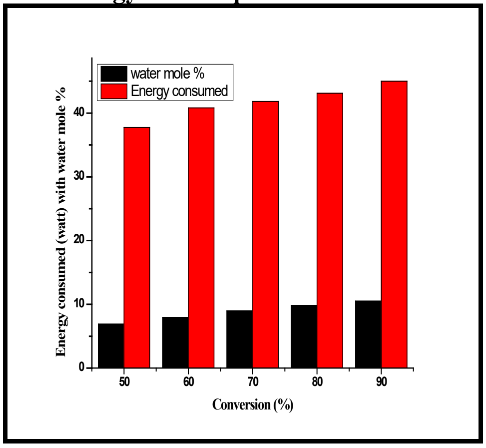

Figure 2b: Effect of conversion on water content and energy consumption at 2.5:1 ratio

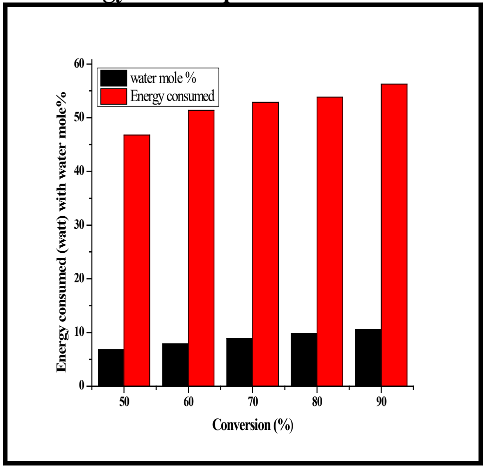

Figure 2c: Effect of conversion on water content and energy consumption at 3:1 ratio

4.3 Effect of weight of silica vs. energy consumption

Figure 4 shows that increase in silica weight increases the thickness of bed. Increasing in the thickness increases the drying time. This is due to more moisture accumulation in the bed which effects declining the drying rate, hence increases the energy consumption[22]. An increment of 5 gm in silica weight increases the energy consumption by 20%.

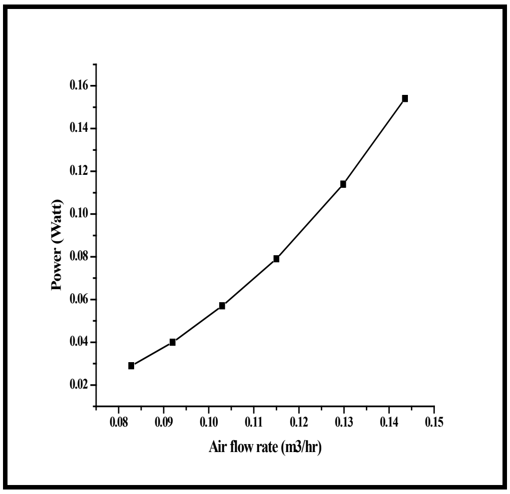

Figure 3a: Effect of air flow reduction on power consumption at 60^{0}C air temp

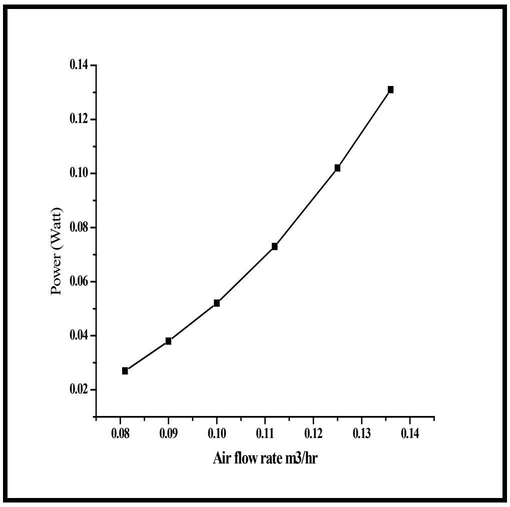

Figure 3b: Effect of air flow reduction on power consumption at 65^{0}C air temp

5. Response Surface Methodology (RSM) Analysis

5.1. Second Order Model Determination

Table 3 depicts the Box Behnken design for three variables (BBD) for three factors using Design Expert software7.0. Table 4 gives the summary of statistics. The statistic suggests using quadratic model as its PRESS value is lowest. Very low R^2 and Adj. R^2 value of the linear and 2FI model is not adequate for experimental data.

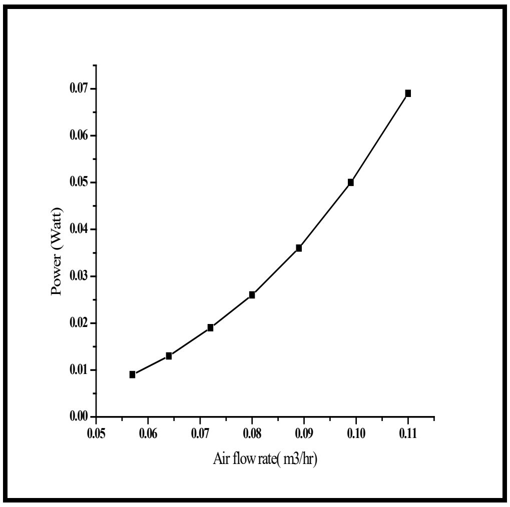

Figure 3c: Effect of air flow reduction on power consumption at 70^{0}C air temp

Table 3: Box Behnken Design for Three Variables

Variables	Symbol	Coded levels		
		-1	0	+1
Molar ratio of alcohol to acid (M)	X_1	2	2.5	3
Silica gel weight (gm)	X_2	20	30	40
Hot air temperature (^{0}C)	X_3	60	65	70

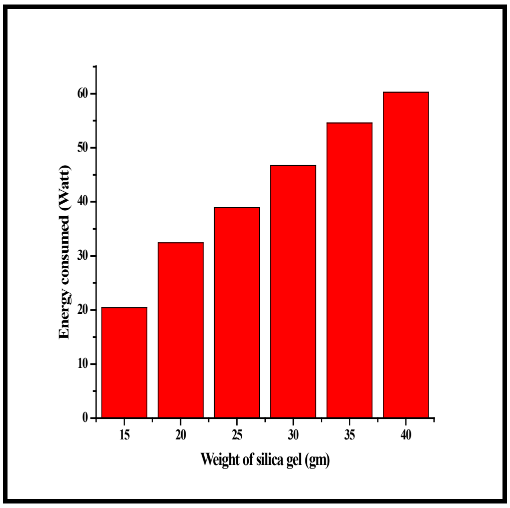

Figure 4: Effect of Weight of silica vs energy consumption

The response was used to propose an empirical model that correlated the response to the energy consumption in the esterification of acetic using a second-degree polynomial equation as given by equation 5. The optimum value of the response was predicted by applying the model equation developed. The interaction between the individual variables was also elucidated.

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i Xi + \sum_{i=1}^{n} \beta_{ii} Xi^2 + \sum_{i=1}^{n} \beta_{ij} Xij + e \qquad (6)$$

where, $\beta_0, \beta_i, \beta_{ii}$ and β_{ij} are the constant of regression coefficients (β_0 refers the constant term, β_i, refers the linear term, β_{ii} refers to the squared term for variable i, and β_{ij} is the interaction term between variable i and j). The response variable used in this study is energy consumption. The n is the total number of variables used to optimize the energy consumption in esterification of acetic acid and e is the random error.

5.2. Model Fitting and Analysis of Variance (ANOVA)

RSM 7.0 was used to design the experiments. In all seventeen runs of experiments were performed to obtain the result which are given in table 5. Multiregression and backward elimination method was used to obtain the fitting model. Table 5 depicts the predicted value of energy consumption.

Table 4: Model Summary Statistics

Model	Std Deviation	R^2	Adjusted R^2	Predicted R^2	PRESS	Suggestion
Linear	34.41	0.1955	0.0098	-0.4945	28590.1	
2FI	23.98	0.6995	0.5192	0.2437	14467	
Quadratic	13.06	0.9376	0.8575	0.4493	10535.5	Suggested
Cubic	12.18	0.9690	0.8759			Aliased

Table 5: Experimental Data and Predicted Values

Run	Experimental Variables			Energy consumption, Watt	
	X_1	X_2	X_3	Experimental	Predicted
1	2	20	60	34.29	38.36
2	2	40	60	32.57	38.36
3	2	30	65	32.14	38.36
4	2	40	65	32.14	33.24
5	2	20	70	31.81	21.80
6	2	30	70	31.81	21.80
7	2	40	70	32.70	38.36
8	2.5	30	60	71.16	70.06
9	2.5	40	60	74.15	80.79
10	2.5	20	65	60.10	38.36
11	2.5	30	65	58.46	47.35
12	2.5	40	65	58.46	69.57
13	2.5	20	70	58.46	61.83
14	3	40	60	122.05	118.68
15	3	30	65	112.77	117.24
16	3	20	70	107.11	102.64
17	3	40	70	129.67	123.03

The quadratic model for predicted and actual value proposed by RSM is expressed as:

$$Y = 38.36 + 8.66X_1 - 19.77X_2 + 1.35X_3 + 15.05X_1^2 + 20.95X_2^2 + 17.47X_3^2 - 15.9X_1X_2 - 39.06X_1X_3 - 25.13X_2X_3 \qquad (7)$$

$$Y = -203.5 + 827.4X_1 + 26.07X_2 - 36.43X_3 + 60.18X_1^2 + 0.2X_2^2 + 0.7X_3^2 - 3.17X_1X_2 - 15.62X_1X_3 - 0.5X_2X_3 \qquad (8)$$

Table 6 represents ANOVA of the regression model. It indicates that R^2 value to be 0.9376, which confims that the model can explain 93.76% of the data variation and only 6.24% of the total variations were not explained by the model. Still this model is considered adequate because adjusted R^2 valueis 0.8574 which is much higher than 0.75[23]. The model is also adequate for prediction in the range ofexperimental variables. According to Chauhan et al, model can be termed as a good statistical model for, R^2 value which is close to 1.0 and all the three factors are positive[24]. The "Lack of Fit F-value" generated by the model is 1.35. This indicates that Lack of Fit is not significant relative to the pureerror. The 37.73% chance of " Lack of Fit F-value" is due to noise. Non-significant lack of fit is always acceptable. "Adeq Precision" measures the signal to noise ratio which is10.10in this case and is desirable. This model can be used to navigate the design space. For a term to be a significant F value is large and $P < 0.05$.

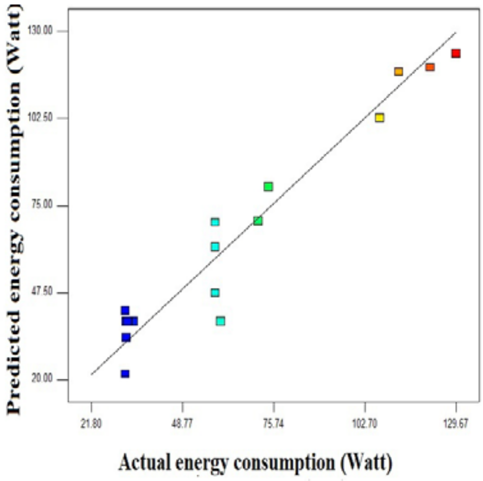

Figure 5: Predicted vs Actual energy consumption

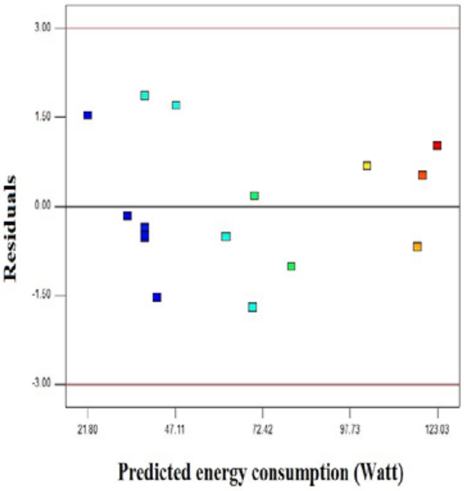

Figure 6: Predicted energy consumption vs residuals

Figure 5 depicts the relationbetween predicted energy consumption by the proposed model vs experimental values. The model successfully adopted the correlation between the process conditions of energy consumption in the esterification of acetic acid and n butanol because the predicted values were in the vicinity of the observed values. A good relationship between actual energy consumption and predicted energy consumption, evaluated from equation indicate that the model is significant. In this one linear term X_2, two quadratic terms $X_2^2X_3^2$ and all three interaction terms X_1X_2, X_1X_3, X_2X_3 are significant. Figure 6 depicts the random distribution of the residuals confirms the absence of a trend. This shows that, the mathematical model is adequate and that there exists consistency between the experimental and estimated values of the response.

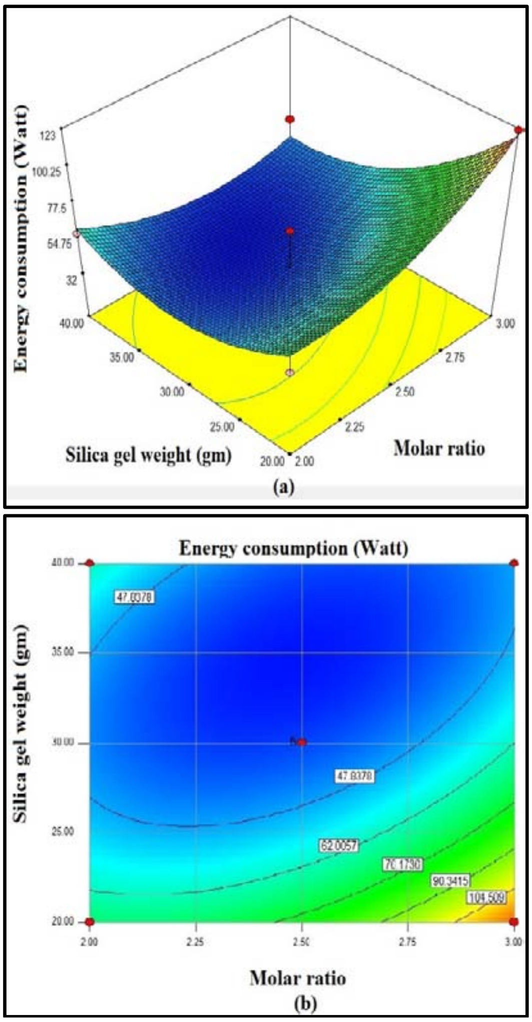

Figure 7: Effect of molar ratio and silica gel weight on the energy consumption, keeping hot air temperature at its optimum value

Increasing the thickness of bed increases the regeneration time. This is due to more moisture accumulation in the bed which results in declining the drying rate, hence increases the energy consumption[22]. However, the further decrease in the bed thickness increases the energy consumption slightly (Figure 7). This may be due to low accumulation of moisture and load imbalance. Elliptical contour plot shows that the interaction of silica gel weight and molar ratio is significant with the lower p value 0. 0451. Also, the least energy was consumed when the molar ratio was 2.5 and the silica gel weight was 25 gm.

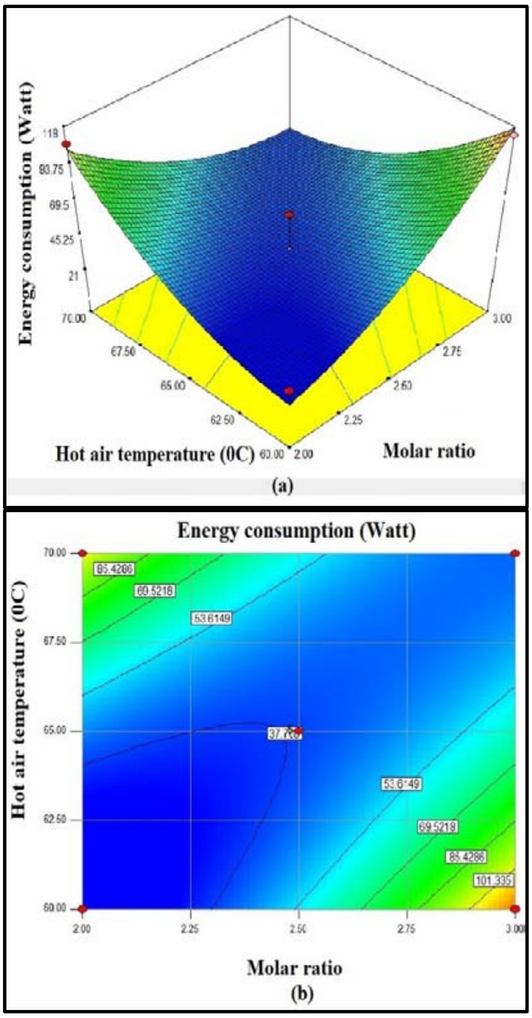

Figure 8: Effect of molar ratio and hot air temperature on the Power, keeping silica gel weight at its optimum value

Molar ratio and hot air temperature have significant effect on the absorption of energy. Figure 8 shows that, increasing the molar ratio the power consumption increases because the mass of reactant is more also the water generated during esterification increases with molar ratio. From the 3D plot it shows the interaction effect the least energy 37.7 was consumed when the molar ratio and hot air temperature was kept in the range of 2.25 to 2.5 and 62^0C to 65^0C respectively. The hot air temperature has inverse relation with the flowrate. Slower the air moves to dry the bed, the warmer the outlet moisture due to lesser contact of inlet hot air on the silica gelsurface[25]. Therefore, moisture removal is improved with low process volume flowrate. This causes to continuous surface renewal to absorb moisture and hence the energy consumption (heat energy) is increased.

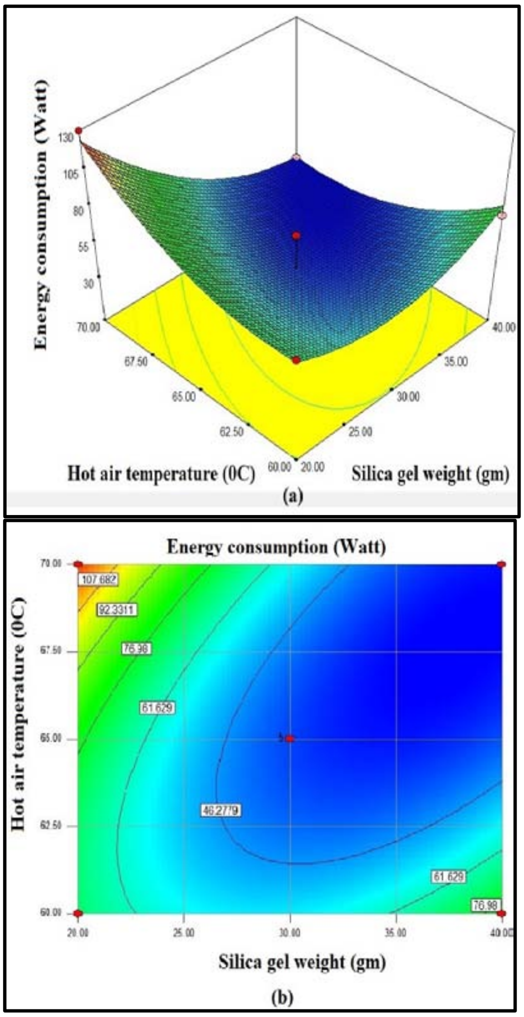

Figure 9: Effect of silica gel weight and hot air temperature on the Power, keeping molar ratio at its optimum value

Figure 9 (a) and 9 (b) shows the interaction of hot air temperature and silica gel weight on energy consumption. As can be seen, increasing the hot air temperature as well as silica gel weight the energy consumption is increased. It might be since with increase in weight increases the bed thickness which eventually increases the distance for the moisture. As in this process the drying rate increases, the further uptake of water ceases for a while which consequently increases the energy consumption. The elliptical contour plot indicated that the combined effect of hot air temperature and silica gel weight was significant. This result is also supported by lower p-value (0.0063) of interaction effect X_2X_3 term.

Table 6: ANOVA Results for Acquired Model

Source	Sum of Squares	Degree of freedom	Mean Square	F-value	p-value prob>F	Characteristic
Model	17935.81	9	1992.87	11.69	0.0019	Significant
X_1	599.51	1	599.51	3.52	0.1029	
X_2	3125.50	1	3125.50	18.33	0.0037	
X_3	14.67	1	14.67	0.086	0.7778	
$X_1 X_2$	1010.92	1	1010.92	5.93	0.0451	
$X_1 X_3$	6103.93	1	6103.93	35.79	0.0006	
$X_2 X_3$	2526.13	1	2526.13	14.81	0.0063	
X_1^2	953.12	1	953.12	5.59	0.0500	
X_2^2	1848.43	1	1848.43	10.84	0.0133	
X_3^2	1285.24	1	1285.24	7.54	0.0287	
Residual	1193.83	7	170.55			
Lack of Fit	600.53	3	200.18	1.35	0.3773	Not significant
Pure Error	593.30	4	148.32			
Cor Total	19129.64	16				

R^2 =0.9376; Adjusted R^2= 0.8574;
Predicted R^2 = 0.4493; Adequate precision=10.107

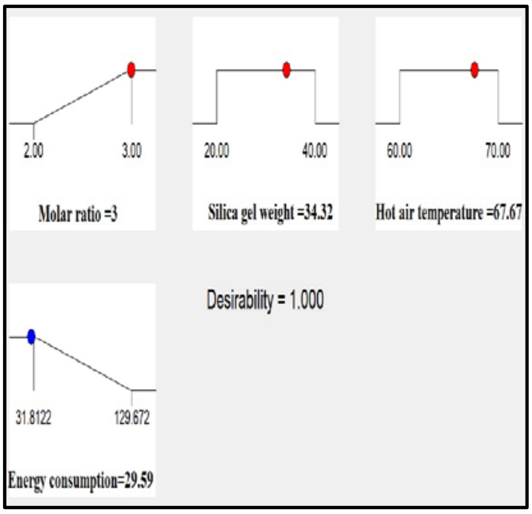

Figure 10: Ramp function graph for normalized condition and response as energy consumption

Figure10 depicts the ramp function graph for energy consumption in esterification of acetic acid with n butanol. It depicts the values of independent parameter to attain the minimum value of energy consumption. The desirability 1 corresponds to the minimum energy consumption in the given range of parameters. When the hot air temperature, molar ratio and silica gel weight were 67.67^0C, 3 and 34.32 gm, then the minimum energy consumption was 29.59 Watt.

5. Conclusions

For any industrial unit the attempt is to keep the specific energy consumption (SEC) as low as possible. It proved to be an effective technique to remove water by using MBAR accompanied by silica gel desiccant. The high content of water as a by product is responsible for more demand of energy consumption. Decrease of 33% in power consumption was observed by decreasing the hot air flow rate by 10%. This is the conformity of validation of affinity law. By increasing the weight of silica by 5 gm there is increase in energy consumption by 20%. The newly invented model was optimized for variables, hot air temperature, molar ratio and silica gel weight. The minimum energy consumption at 1 desirability was reported by software in the given range of parameters. When the hot air temperature, molar ratio and silica gel weight were 67.67^0C, 3 and 34.32 gm, then the minimum value of energy consumption was 29.59 Watt.

Nomenclature

Hr: Heat of reaction (KJ/Kmol K)
C: Heat capacity constants
Toe: Tonnes of oil equivalent
SEC: Specific energy consumption
$n_{af:}$ Moles of acetic acid
$T_{r:}$ Reaction temperature (K)
T: Reaction time (min)
W_s: Weight of silica (gm)
$Q_{w:}$ Mass of outlet water (ml)
M%: Moisture %
$Q_{a:}$ Flowrate of air (m^3/hr)
P: Power (watt)

References

[1] Jadhav, S.B., G.P. Jadhav, and S.N. Teli. Steel Industries and Six Sigma, Int. J. Sci. & Eng. Res. 5(12):2014.

[2] Mandal, S.K., and S. Madheswaran. Energy Use; Efficiency in Indian Cement Industry: Application of Data Envelopment Analysis and Directional Distance Function.2009.

[3] Shaikh, MZ. Energy Conservation Opportunities & GHG Reductions in Textile Cluster. Int. J. Sci. & Res Pub**,** 7(11): 494-501,2017.

[4] Tgarguifa A., SAbderafi, and T. Bounahmidi. Response Surface Optimization of Bioethanol Production Based on Process Simulation of Distillation.IEEE,*978-1-4673-7894-9,*2015

[5] Dan, S., N. Dan, and T.K. Pal. Application of Response Surface Methodology(RSM) in Statistical Optimization and Pharmaceutical Characterization of a Matrix Tablet Formulation Using Metformin HCL as Model Drug, Inn original Int. J. Sci. 1(2):1-6,2014.

[6] Kohli, A., and H. Singh. Optimization of Processing Parameters in Induction Hardening Using Response Surface Methodology*,* Indian Sadhana,36(2),141-152,2011.

[7] Sarah, M., I. Madinah, S. Salamah. Response Surface Methodology to Optimize Microwave Sterilization of Palm Fruit, 2nd International Conference on Statistics, Mathematics, Teaching, and Research. J. Physics. doi:10.1088/1742-6596/1028/1/012004.

[8] Khayet, M., C. Cojocaru, and C. Garcia-Payo. Application of Response Surface Methodology and Experimental Design in Direct Contact Membrane Distillation, Ind. Eng. Chem. Res. 46:5673-5685,2007.

[9] Ahmad, M.J., and S.K. Theydan, Optimization of Microwave Preparation Conditions for Activated Carbon from Albizialebbeck Seed Pods for Methylene Blue Dye Adsorption J. Anal. Appl. Pyrol.105:199-208, 2014.

[10] Ezechi, E.H., S.R.B.M. Kutty, A. Malakahmad, and M.H. Isa. Characterization and Optimization of Effluent Dye Removal Using a New Low Cost Adsorbant: Equilibrium, Kinetics and Thermodynamic Study. Process Saf. Environ prot.98**:**16-32, 2015.

[11] Krishnaiah, D., A. Bono, R. Sarbatly, R. Nithyanandanam, and S.M. Anisuzaman. Optimization of Spray Drying Operating Conditions of Morinda Citrifolia L. Fruit Extract Using Response Surface Methodology. J. King Sad. Uni. Eng.Sci.27:26-36, 2015.

[12] Betiku, E., S.S. Okunsolawo, S.O. Ajala, and O.S. Odedele, Performance Evaluation of Artificial Neural Network Coupled with Genetic Algorithm and Response Surface Methodology in Modelling and Optimization of Biodiesel Production Process Parameters from Shea Tree (Vitellariaparadoxa) Nut Butter.Ren.Energy.76:408-417,2015.

[13] Liao, C-C., and T-W. Chung. Optimization of Process Conditions Using RSM for Microwave Assisted Transesterification of Jatropha Oil with KOH Impregnated CaO as Catalyst. Chem. Eng. Res. and Design.91**:** 2457-2464, 2013.

[14] Chandane, V., A.P. Rathod, K. Wasewar, and S. Sonawane.2016.Esterification of Propionic Acid with Isopropyl Alcohol over Ion Exchange Resins: Optimization and Kinetics. Korean J. Chem. Eng*,* 34**(**1**),** 249-258, 2017.

[15] Touma, J.G., B.E. Khoury, J. Estephane H. Zakhem, and S. Aouad. Effect of Alcohol Type and Amount on the Total Energy Consumption and Yield of the Free Fatty Acids: Esterification Reaction with Simultaneous Adsorptive Water Removal. Chem. Eng. Commu.doi org/10.1080/00986445.2017.1412312.

[16] Kelkar, M.A., P.R. Gogate, and A.B. Pandit. Intensification of Esterification of Acids for Synthesis of Biodiesel Using Acoustic and

Hydrodynamic Cavitation, Ultrasonic Sonochemistry.15**:**188-194, 2008.

[17] Beery, K.E., and M.R. Ladisch. Adsorption of Water from Liquid-Phase Ethanol-Water Mixtures at Room Temperature Using Starch-Based Adsorbents. Ind. Eng. Chem. Res. 40: 2112-2115,2001.

[18] Pahl, C., C. Pasel, M. Luckas, and D. Bathen, Adsorptive Water Removal from Primary Alcohols and Acetic Acid Esters in the ppm-Region. J. Chem. Eng. Data.57:2465-2471.2012.

[19] Aranda, D.A.G., R.T.P. Santos, N.C.O. Tapanes, A.L.D. Ramos, and O.A.C. Antunes. Acid Catalysed Homogeneous Esterification Reaction for Biodiesel Production from Palm Fatty Acids Catal. Lett.122:20-25.2008.

[20] General Aspects of Energy Management and Energy Audit, Guide book 1 for National Certification Examination for Energy Managers and Energy Auditors, BEE.

[21] Perry’s Chemical Engineer’s Handbook Seventh Edition

[22] Barlow, R., and K. Collier, Optimizing the Performance of Desiccant Beds for Solar Regenerated Cooling. SERI/TP/631-1157 UC Category, UC -59

[23] Man, H.Le., S.K. Behera, and H.S. Park. Optimization of Operational Parameters for Ethanol Production from Korean Food Waste Leachate.Int. J. Environ. Sci. Technol. **7**(1**)**, 157-164,2010.

[24] Chauhan, B., and R. Gupta. Application of Statistical Experimental Design for Optimization of Alkaline Protease Production from Bacillus Sp. RGR-14.Process Biochemistry, 39:2115-2122, 2004.

[25] Alahmer, A. Alsaqoor, S, and Borowski, G. Effect of Parameters on Moisture Removal Capacity in the Desiccant Cooling Systems. Case Studies in Thermal Eng. doi.org/10.1016/j.csite.2018.11.015