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Effect of Additional Concentration of ATMP Inhibitor on The Formation of 40% Phosphoric Acid Scale

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Abstract. Calcium sulfate ($CaSO_4$) scale formation during the phosphoric acid (H_3PO_4) production process presents significant operational challenges. Key variables influencing scale formation include temperature, pressure, stirring speed, and supersaturation. This study aims to evaluate the effect of varying concentrations of ATMP inhibitors on the mass of $CaSO_4$ scale in a 40% phosphoric acid solution and to analyze the composition of the resulting scale. The experimental procedure involved the addition of ATMP inhibitors at different concentrations, while temperature and stirring speed were varied. The solution was circulated through a sample housing for two hours, after which the mass of the formed scale was measured, and X-Ray Fluorescence (XRF) analysis was performed. The optimal concentration of ATMP inhibitors was found to be 9 ppm at a temperature of 40°C and a stirring speed of 235 rpm. Results indicated that the composition of the $CaSO_4$ scale produced with ATMP inhibitors was significantly lower than that of samples without inhibitors, with XRF analysis revealing an 8% reduction in $CaSO_4$ levels.

Introduction

Scale formation is a significant issue commonly found in pipelines. In the phosphoric acid (H_3PO_4) industry, scale formation, particularly from calcium sulphate ($CaSO_4$), poses a serious problem. The accumulation of this scale can lead to the narrowing of the pipeline diameter, which in turn can reduce the pipeline's performance by slowing down the flow rate and impairing heat transfer within the pipe [1]. The formation of scale is influenced by several factors, including temperature changes, supersaturation, concentration changes, and agitation [2].

In the phosphoric acid industry, heat exchangers are used for heating, with steam temperatures of 133°C on the shell side and 90°C on the tube side, through which 40% phosphoric acid flows. The presence of $CaSO_4 \cdot 1/2H_2O$ formed during the initial stages of the hemihydrate reaction, combined with the operating conditions of the heat exchanger at temperatures above 37°C, causes supersaturation of the phosphoric acid, leading to the formation of scale crystals [3]. The existence of this scale if it continues will cause disruption of the production process such as narrowing the fluid flow in industrial equipment which results in an increase in temperature and pressure, which can cause pipe rupture [4].

The presence of scale on the heat exchanger is often solved by periodic water cleaning by shutting down the factory production process for 7 to 14 days. This results in high costs and reduces production optimization. Therefore, other alternatives are needed in the form of scale inhibitors to prevent the process of scale formation. There are several kinds of inhibitors commonly used in industry, including inorganic and organic compounds. Many organic compounds used as inhibitors contain phosphates such as polyphosphates, phosphonates, polycarboxylates, aminotris trimethylenephosphonic acid (ATMP), diethylenetriamine pentamethylene phosphonic acid (DTPMP), etc [5].

ATMP is an environmentally friendly organic phosphonate compound used in open water circulating cooling systems, petroleum pipelines and boilers as a scale and corrosion inhibitor [6]. The way these inhibitors work in suppressing the rate of scale growth is by binding and coating scale-forming cations into chelate compounds that will dissolve in water. The inhibitor will then adsorb on the smooth crystal surface and react to form a chelate [7]. According to [8] ATMP performs better than other corrosion inhibitors such as polyacrylic acid (PAA) and polyamino polyether methylenephosphonate (PAPEMP). Of the three inhibitors, ATMP does not require a large dose to achieve inhibition efficiency on scale, which is between 5-10 ppm. In addition [9] also proved that at a concentration of 25 ppm ATMP has the best performance when compared to diethylenetriamine penta (methylene phosphonic acid) (DTPMP), Phospono Butane Tricarboxylic Acid (PBTC), ethylenediamine tetra (methylene phosphonic acid) (EDTMP) and Hexamethylene-diaminetetra (methylene phosphonic) acid (HDTMP).

In this research, the performance and efficiency of ATMP inhibitor in phosphoric acid 40% has not been known. Therefore, this research was carried out with the aim of determining the minimum scale mass in phosphoric acid solution from the effect of changes in ATMP inhibitor concentration, temperature and stirring speed and knowing the effect of ATMP inhibitor addition on the quality of phosphoric acid solution through XRF analysis of the composition of the crust formed.

Materials and Methods

The research methodology aims to evaluate the effect of varying concentrations of ATMP inhibitor on the formation of calcium sulphate ($CaSO_4$) scale in a 40% phosphoric acid solution flow system. The study was conducted using a scale formation simulator developed based on the research methodology of[10].

The materials used in this research is aquades, ATMP inhibitors, calcium chloride ($CaCl_2$), sodium sulphate (Na2SO4). The dependent variables include an operating pressure of 1 atm, a solution volume of 500 mL, and a flow rate of 60 mL/min. The independent variables consist of ATMP inhibitor concentrations (1, 3, 6, 9, and 11 ppm), phosphoric acid solution temperatures (33°C, 40°C, 50°C, 60°C, and 67°C), and agitation speeds (140 rpm, 238 rpm, 381 rpm, 525 rpm, and 623 rpm). Various tools and materials were utilized in the study, including sandpaper, a storage tank, beaker glasses, an oven, measuring cylinders, a heater, copper pipes, an XRF analysers, pipettes, pumps, heat-resistant hoses, an electric scale, and valves.

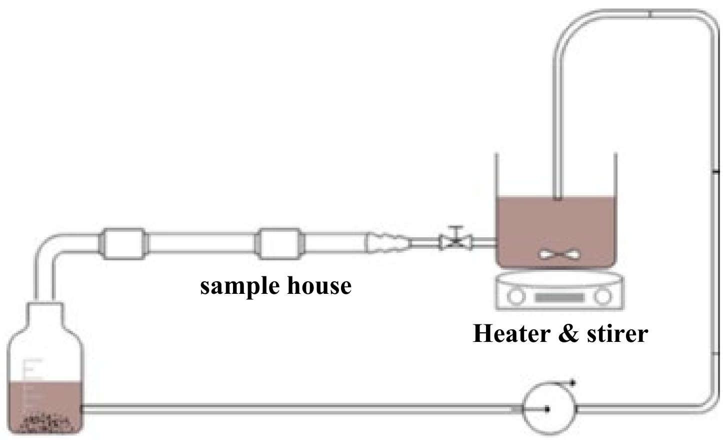


Fig. 1 Schematic of the Scale Forming Process Simulator Tool

The experimental procedure begins with the preparation of equipment, which consists of two containers: a 500 mL beaker and a 1-liter collection tank. The beaker is used to mix $CaCl_2$, Na_2SO_4, and the inhibitor solution of ATMP according to the predetermined variables. The sample housing pipe serves as the medium for scale formation, with the flow rate of the sample being controlled using a valve or faucet on the outlet of the sample pipe. The fluid flow in the collection tank is then recycled back to the beaker using a pump during the 2-hour experiment.

To prepare the 40% phosphoric acid solution, first measure 230 mL of 85% phosphoric acid using a graduated cylinder, then transfer it to the beaker and add distilled water until the total volume reaches 500 mL. Next, to prepare the 0.7% $CaCl_2$ and Na_2SO_4 mixture, weigh out 9.71 grams of $CaCl_2$ and 12.42 grams of Na_2SO_4, then add them into the beaker containing the 500 mL phosphoric acid and distilled water mixture. Afterward, turn on the hot plate stirrer to mix the solution until it becomes homogeneous.

Determining Experimental Design Using Minitab. The efficient design and analysis of experiments necessitate the use of Design of Experiment (DOE). The primary objective of DOE is to comprehend the cause-and-effect relationship between input factors (independent variables) and responses (dependent variables) within a system or process. In this research, the ATMP inhibitor concentration, temperature, and stirring speed are considered as input factors, with precipitate weight being the response. In Minitab Software, DOE achieves this by initially creating a response surface design. Subsequently, decisions are made regarding the number of factors to incorporate and the selection of experiment designs.

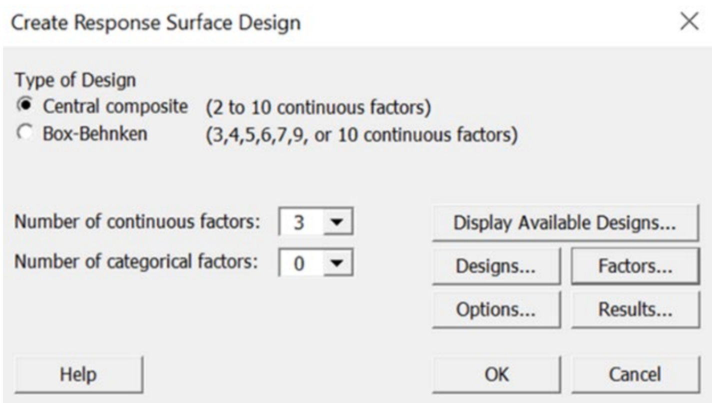
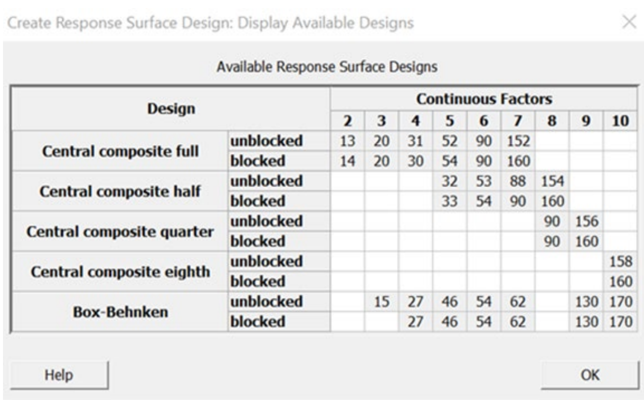


Fig. 2. Display Response Surface Design on Minitab

This study employs Central Composite Design (CCD) for experimental analysis. On the create response surface design menu, CCD is selected by entering the number of continuous factors 3. This is because there are 3 factors tested in this research, namely the concentration of inhibitors in ppm, temperature, and stirring speed in rpm. After selecting the design type, then click the "Designs" button, then choose how much research will be done.


Create Response Surface Design: Display Available Designs

Available Response Surface Designs

Design		Continuous Factors								
		2	3	4	5	6	7	8	9	10
Central composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

Help OK

Fig. 3. Multiple Response Surface Design Experiment Options on Minitab

Then, click “OK” and return to the create response surface design menu. Then, click the “Factors” button to enter the upper and lower limits of the variables to be experimented, Then, click “OK” again.

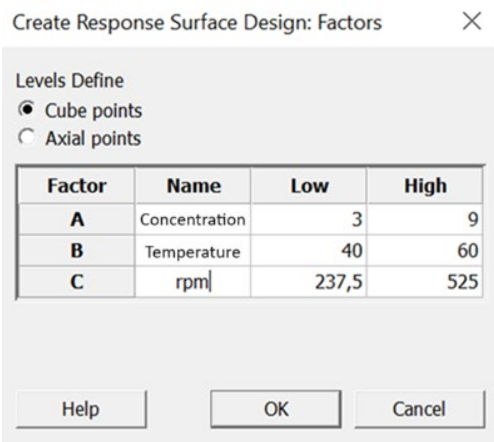


Fig. 4. Display of Menu Factors in Create Response Surface Design in Minitab

Then, go back to the create response surface design menu, after that select “Designs” and select center points and alpha values according to the default.

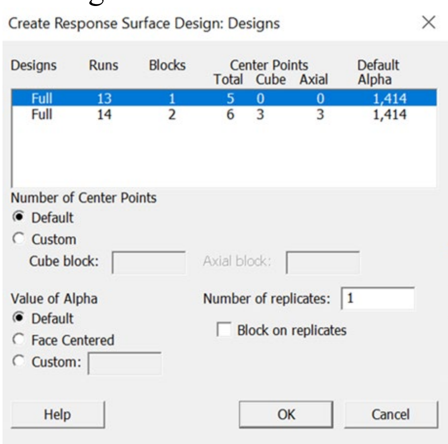
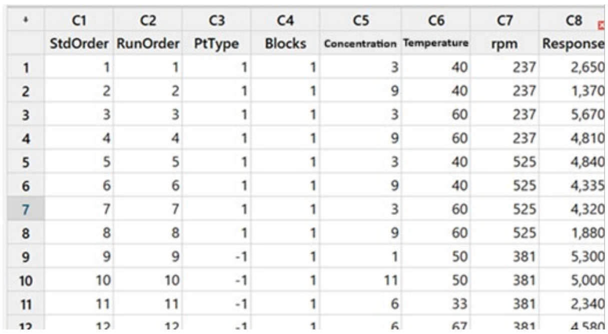


Fig. 5. Display of Center Points and Alpha Value Selection on Minitab

After clicking "OK", the results of the combination of experimental designs will appear on each factor. Then, add the *response* column as a column for input of scale deposits after the experiment. In the results of the experimental design using the RSM method, it produces 2 new variables in each factor. In the factor of increasing the concentration of ATMP inhibitors there is an addition of variables 1 and 11 ppm, in the temperature factor there is an addition of variables 33°C and 67°C and the stirring speed factor there is an addition of variables namely 140 and 623 rpm. In the RSM method, the response variable is modeled as a function of the input variable, and the goal is to find the optimal input value that maximizes or minimizes the response variable. The upper and lower bounds of response variables are important because they determine the range of values that response variables can take, and they can be used to identify *outliers* or unusual observations in data [11] [12].



	C1 StdOrder	C2 RunOrder	C3 PtType	C4 Blocks	C5 Concentration	C6 Temperature	C7 rpm	C8 Response
1	1	1	1	1	3	40	237	2,650
2	2	2	1	1	9	40	237	1,370
3	3	3	1	1	3	60	237	5,670
4	4	4	1	1	9	60	237	4,810
5	5	5	1	1	3	40	525	4,840
6	6	6	1	1	9	40	525	4,335
7	7	7	1	1	3	60	525	4,320
8	8	8	1	1	9	60	525	1,880
9	9	9	-1	1	1	50	381	5,300
10	10	10	-1	1	11	50	381	5,000
11	11	11	-1	1	6	33	381	2,340
12	12	12	-1	1	6	67	381	4,580

Fig. 6. Results of Experimental Design Display on Minitab

The preparation of the ATMP inhibitor solution involves creating solutions of ATMP inhibitors at concentrations of 1, 3, 6, 9, and 11 ppm. This is achieved by preparing a mother solution containing 100 ppm ATMP, wherein ATMP inhibitors are dissolved in a quantity of 0.2 ml within a volume of 1000 ml of aquades. This observation was made with five different ATMP inhibitor concentration treatments. The dilution of inhibitors of 11 ppm concentration to 1, 3, 6, and 9 ppm refers to the dilution formula.

In this research, 9.71 grams of $CaCl_2$ and 12.42 grams of Na_2SO_4 were put into a beaker until both compounds were homogeneous by adjusting the temperature and stirring speed that had been set, then adding ATMP inhibitors according to the variables. If the heater has reached the set temperature, open the flow valve to the sample housing. The sample house is a component for which scale deposition of calcium sulfate ($CaSO_4$) is expected. The flow velocity leaves the sample exactly according to the design, which is 6.0 ml/min. The flow that has passed through the sample house will be accommodated in a reservoir which will then be recycled back to the beaker glass.

After two hours of experimentation, the tap to the channel of the sample house was closed. An hour later, the sample house is taken and dried in the oven at a temperature of 70ºC for eight hours. Inside the sample housing, the solution begins to react to form a crust. The difference between the mass of the sample house and the crust in the dry state minus the mass of the sample house without scale is the mass of the crust itself. With the same treatment, experiments continue to be carried out according to the variables of ATMP inhibitor concentration, solution temperature, and stirring speed.

Determination of Minitab Optimization Results involves incorporating the recorded scale deposit results into the Minitab response column, conducting surface design analysis, creating contour plots, and understanding the optimization achieved by the response optimizer.

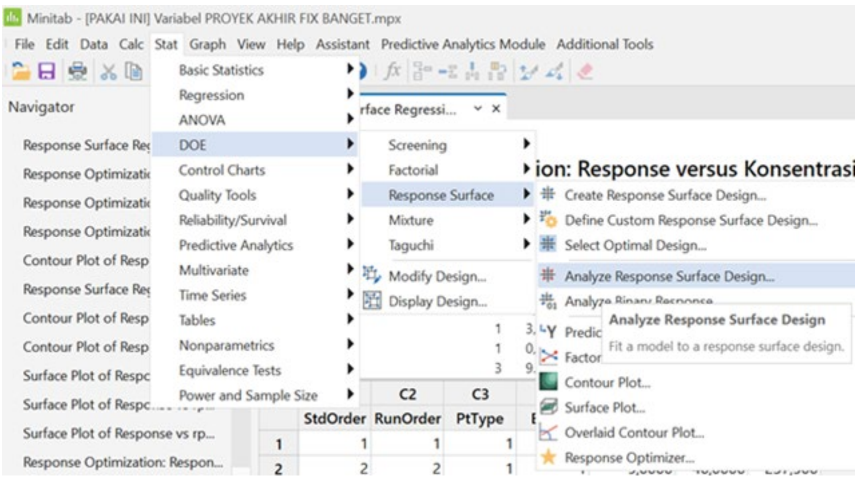


Fig. 7. Minitab Menu Display to Know the Results of the Research Analysis

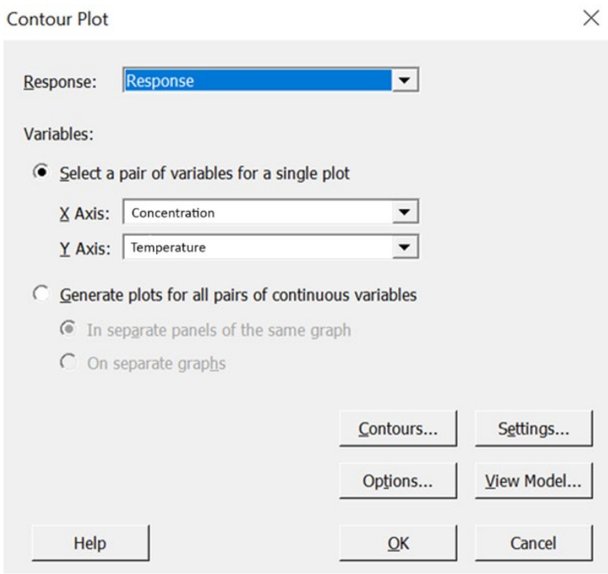


Fig. 8. Minitab Menu Display to Know the Contour Plot Resulting from the Experiment

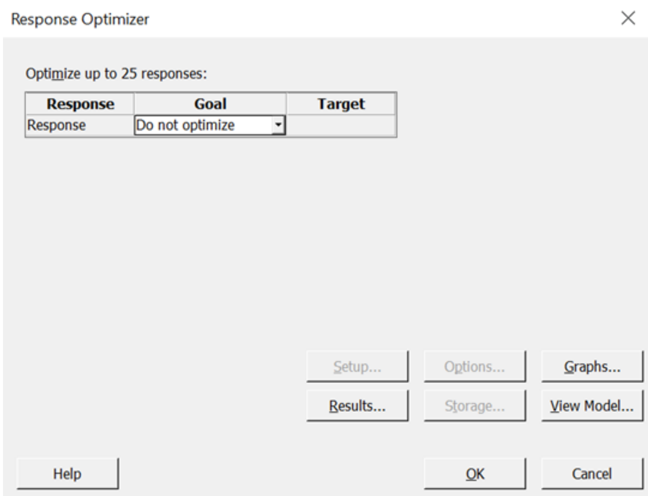


Fig. 9. Minitab Menu Display to Know the Optimization Response Resulting from the Experiment

Analysis using XRF is performed based on the identification and enumeration of X-ray characteristics that occur from photoelectric effect events. Photoelectric effects occur because electrons in the target atom (sample) are exposed to a high-energy beam (gamma radiation, X-rays). If the energy of the beam is higher than the binding energy of the electrons in the K, L, or M orbits of the target atom, then the electrons of the target atom will exit their orbits. Thus, the target atom will experience an electron vacuum. This electron void will be filled by electrons from the outer orbitals followed by the release of energy in the form of X-rays [13].

The X-rays produced are a combination of a continuous spectrum and a certain energy spectrum (discreet) derived from the target material that is pounded by electrons. The type of *discreet* spectrum that occurs depends on the transfer of electrons that occur in the atoms of the material. This spectrum is known as the characteristic X-ray spectrum. XRF spectrometry utilizes X-rays emitted by the material which are then captured by the detector to analyze the elemental content in the material. The material analyzed can be massive solids, pellets, or powders. Elemental analysis is carried out qualitatively and quantitatively. Qualitative analysis analyzes the type of element contained in the material and quantitative analysis is performed to determine the concentration of elements in the material. X-rays produced from events such as those mentioned above are captured by a Silicon Lithium (SiLi) semiconductor detector [13].

Result and Discussion

The solubility of $CaSO_4$ in phosphoric acid is influenced by various factors such as acidity, the presence of other solutes, and temperature [14]. mentioned that the solubility of $CaSO_4$ in water with a temperature of 25ºC is about 0.21%. However, after a trial with the same concentration of $CaSO_4$ in 40% phosphoric acid solution obtained by mixing $CaCl_2$ and Na_2SO_4 in a ratio of 3:4, it is still soluble in water. So in this experiment, the concentration of $CaSO_4$ was increased to 0.7%.

The result of MINITAB design to find the optimization of 0.7% $CaSO_4$ solution with the addition of 3, 6, 9 ppm ATMP inhibitor, temperature of 40, 50, 60ºC, and rotating speed of 238, 381, and 525 rpm, first running the experimental variables on Minitab software. This is done to determine the design of experiment (DOE). DOE in RSM serves to explore the relationship between several explanatory variables and one or more response variables. The main objective of RSM is to develop, improve, and optimize the process of determining the optimum formulation [15]. In this case, the variables of concentration, temperature and rotating speed are the factors that will be experimented with to produce a response in the form of sediment weight.

After running DOE on Minitab software, new upper and lower limits were obtained for each factor. The concentration factor obtained an upper limit of 11 ppm and a lower limit of 1 ppm. Then the temperature factor obtained an upper limit of 67ºC and a lower limit of 33ºC. While the stirring speed factor obtained an upper limit of 623 rpm and a lower limit of 139 rpm.

The upper and lower limits obtained serve to provide an upper limit referring to the maximum permissible value for the factor being tested. Factor values above the upper limit may not affect the response or may even produce undesirable results. For example, if the factor being tested is temperature in a chemistry experiment, the upper limit may indicate the maximum temperature at which it is safe to carry out the experiment. The lower limit, on the other hand, refers to the minimum permissible value for the factor being tested. Factor values below the lower limit may not give relevant results or may cause uncertainty in the experimental results. Using the previous example, a lower limit for temperature could indicate the minimum temperature required for a chemical reaction to occur [16].

After obtaining the experimental design from Minitab software, an experiment was conducted by circulating $CaSO_4$ solution in the pipe (sample house) for 2 hours. The experiment was conducted to determine the amount of scale formed by the factors of ATMP inhibitor addition, temperature treatment and stirring speed. Then, a response was obtained in the form of the weight of the scale deposits formed on the pipe (sample house). The results of this research are shown in Figure 10. and Figure 11. The resulting scale deposits were then analysed by XRF which are presented in Table 9 and Table 10.

The plot of the response surface method (RSM) optimization results was conducted to show the effect of $CaSO_4$ scale mass formation in 40% phosphoric acid solution caused by the relationship between concentration, temperature, and stirring speed. The plot used was a contour plot containing the predictors on the x and y axes. Contour lines connect points that have the same response value and colored contours show the range of response values produced.

After that we know about contour plot of concentration vs temperature. In industry, $CaSO_4$ scale formation is a common event that can occur especially in heat exchanger equipment. This formation can potentially occur in piping systems that are passed by solutions with high concentrations of calcium sulphate. Several factors can influence the formation of calcium sulphate scale such as temperature and concentration. The following contour plot shows the effect of these two factors on scale mass formation:

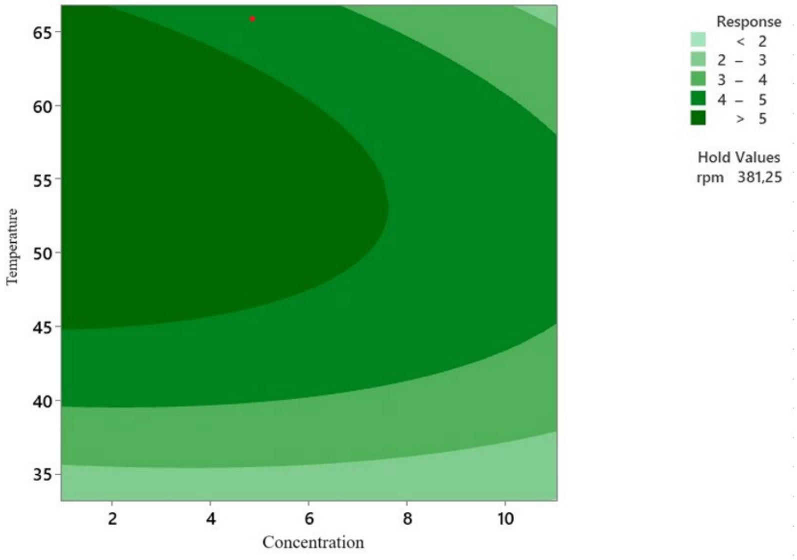


Fig. 10. Contour Plot of Factor Relationship of ATMP Inhibitor Concentration and Temperature on $CaSO_4$ Scale Mass Response

The contour plot above shows the results of the combination of factors between ATMP inhibitor concentration and temperature on $CaSO_4$ scale formation. The results of the magnitude of the response to temperature conditions and the addition of concentrations are described by colour. The more intense the green colour indicates that more scale is produced. In the contour plot above, the most intense green colour indicates a response result of more than 5. While the smallest response is produced with a weight of less than 2 grams.

The combination of high temperature with low concentration produces a large crust mass response of more than 5 grams. The response results changed as the inhibitor concentration and temperature increased. This condition is due to the increase in solution temperature (45ºC - 65ºC), the formation of more $CaSO_4$ scale. The increase in temperature will cause the reaction speed to increase which causes a decrease in induction time at saturation level conditions [17].

The addition of ATMP inhibitor concentration affects the formation of scale mass. In Figure 4.1, the countur plot shows that at high temperature conditions there is a decrease in scale mass along with the increase in ATMP inhibitor concentration. The effect of adding ATMP inhibitor additives can prevent scale formation when added at high concentrations. The efficiency of ATMP inhibitors has a "threshold effect" which has a certain concentration limit in its performance [18]. In this research, the "threshold effect" has not been obtained, so further experiments are needed to reach the threshold in 40% phosphoric acid solution.

The contour plot depicts the relationship between concentration and stirring speed. The outcomes illustrating the extent of the response to variations in rotation speed and added concentration are represented through color-coded plots.The more intense the green colour indicates that more crust is produced. Conversely, the lighter the green colour and the appearance of blue areas indicate that the crust response is less, in the contour plot above it is shown that the smallest precipitate weight produced is less than 3 grams and the largest is more than 5.5 grams. In the contour plot above, the most intense green colour indicates the response results are more than 5. Stirring speed is included in the factors that affect the formation of calcium sulfate crust. As Figure 10. shows, the largest $CaSO_4$ scale formation occurs in the stirring speed range of 250 rpm to 580 rpm with low ATMP inhibitor concentration. However, in this combination of factors, it can be seen that the stirring speed does not have much effect on the crust mass results. The increase in stirring speed is in line with the increase in crust mass, agitation can accelerate the reaction so that the formation or growth of crystals becomes more [19]. This ability of ATMP inhibitor at high concentrations significantly inhibits the formation of calcium sulphate scale.

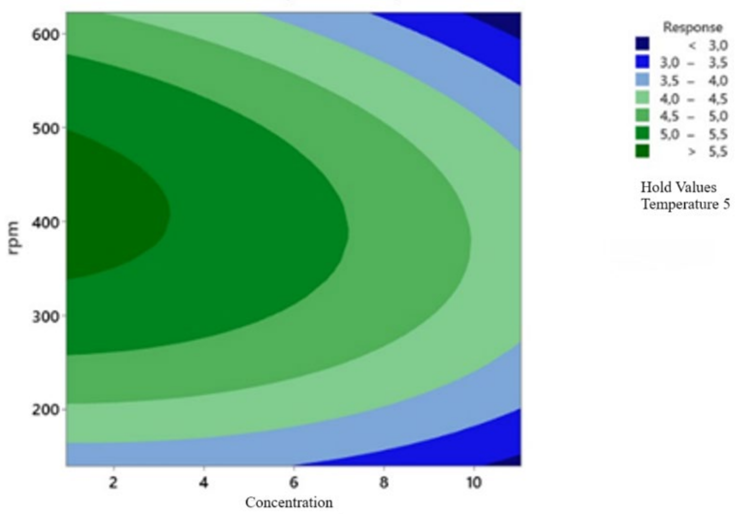


Fig.11. Contour Plot of the Relationship between ATMP Inhibitor Concentration and Stirring Speed to $CaSO_4$ Scale Mass Response

The effect of adding inhibitors can prevent crystal formation from the beginning, where at the secondary nucleation stage small crystals that begin to form will be prevented or inhibited by the ability of ATMP inhibitors. This prevention process causes small crystals of about 10µ in size to be difficult to form towards larger crystals [20].

The results of condition optimization using Response Surface Methodology (RSM), widely applied for data optimization, involve a mathematical and statistical model. This model is utilized to analyze situations in which multiple variables impact the response variable. This method is used to model and analyses a response y that is influenced by several independent variables or factors x as optimization of the response [21]. Based on the research results, the crust mass response has the lowest value of 1.37 grams and the largest value of 5.67 grams. The results of the research optimisation using the RSM method are shown in the figure below.

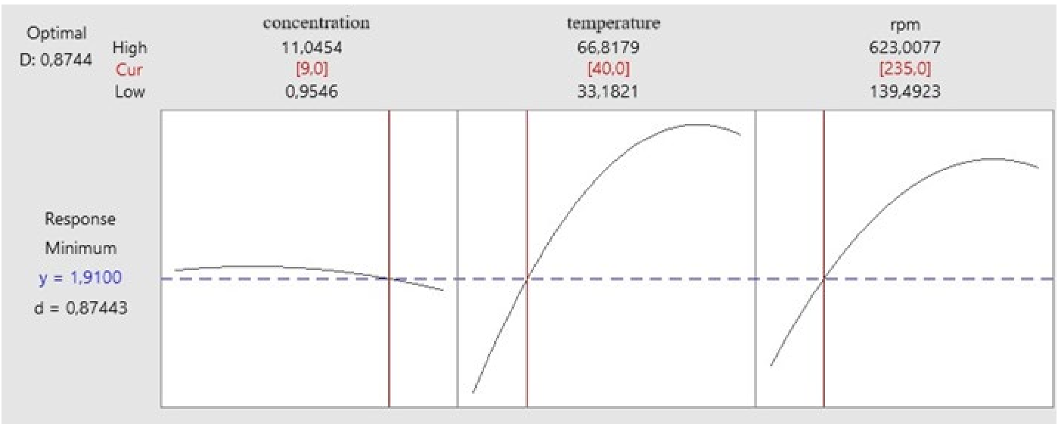


Figure 12. Process Optimisation Results on $CaSO_4$ Scale Mass Formation

The optimisation result in Figure 4.3 is an optimal result of the response optimisation process determined by statistical analysis. The crust mass response optimisation value of 1.9 grams is obtained from the combination of concentration, temperature, and stirring speed factors of 9 ppm, 40ºC, and 235 rpm respectively at certain predetermined limits. In addition to these three factors, scale formation is influenced by several main factors including changes in reservoir conditions, reservoir pressure and temperature changes, mixing of two types of water that have incompatible mineral composition, supersaturation, evaporation due to changes in concentration, stirring (agitation, influence of turbulence), contact time between scale and pipe surface and changes in water pH [20].

The low scale mass value is in accordance with the influence of the three factors under conditions of high inhibitor concentration with low temperature and rpm. Inhibitors function as inhibitors of crystal formation by slowing the rate of formation, increasing heterogeneous nucleation control and stabilising scale deposits. As for calcium sulphate, it has a high solubility under temperature conditions of 30ºC-40ºC, so it tends to produce a low scale mass [22]. While the mass of crust formed is small at low stirring speeds due to the acceleration of reactions between compounds. [19].

Results of Scale Mass Decrease upon the Addition of Inhibitor Concentration. This study investigates the reduction in $CaSO_4$ scale mass in response to the addition of ATMP inhibitor concentration, temperature, and stirring speed. The results in this research were also optimized using Response Surface Methodology (RSM). In general, the value of inhibitor concentration will increase the ability to inhibit scale formation. Thus, the $CaSO_4$ scale formation process will decrease along with the change in ATMP inhibitor concentration. The graph below will show the results of the scale mass of each concentration with a fixed temperature and stirring speed.

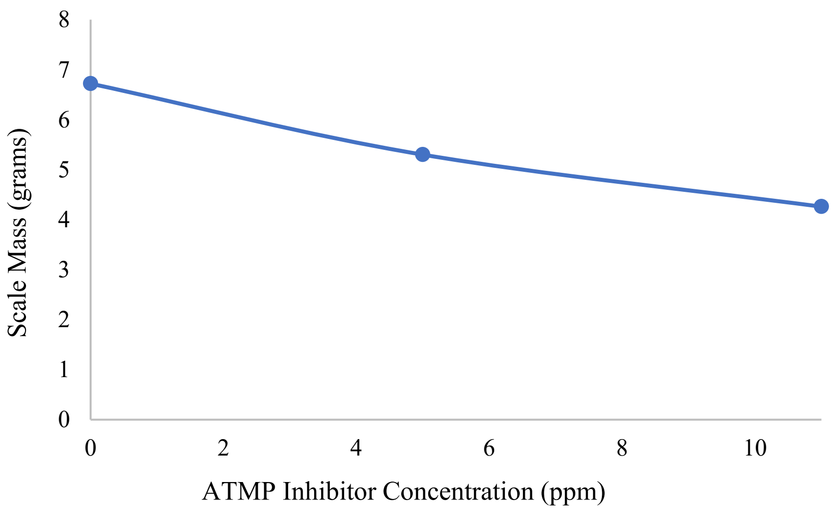


Fig. 13. Effect of Concentration on $CaSO_4$ Scale Formation

The graph above is a presentation of the concentration of 0 ppm, 5 ppm, and 10 ppm under conditions of temperature 50ºC and stirring speed 381 rpm with a scale mass of 6.7 grams; 5.4 grams; and 4.2 grams which shows the results of the trend of decreasing scale mass from the smallest to the largest concentration. ATMP inhibitors are included in the inorganic polyphosphate additive which is a non-crystallised inorganic solid, this substance has advantages in its slower solubility process and can provide the required concentration for a long period of time [23]. Other literature also states that the performance of additives can capture Ca^{2+} ions so that crystal formation is inhibited, so that the reaction rate of scale formation can be inhibited and suppress the formation of $CaSO_4$ scale [20].

Characterization of dry precipitate results with XRF. The analysis conducted using the XRF instrument aims to determine the composition of a solid sample. The results of the crust sample analyzed by XRF are samples obtained from the results of the research using optimization conditions, namely the addition of 9 ppm of ATMP inhibitor at 40ºC and a rotation speed of 235 rpm. To measure the performance of the inhibitor, an experiment was also conducted without the use of inhibitors. Both were carried out using the same temperature operating conditions at 50ºC and a rotation speed of 381 rpm. After XRF analysis, the composition of the scale is displayed in the mass fraction of elements or oxide compounds. The results of the analysis of the composition of scale deposits in phosphoric acid solution are shown in Table 1.

Table 1. Compound Composition Analysis Results of Precipitate Using XRF Instrument

Component	Mass Fraction (%)	
	Using Inhibitors	**without Inhibitor**
P_2O_5	39,45	35,65
SO_3	27,75	28,6
CaO	32	35

Table 1. shows the XRF analysis results of the scale deposits found in the research. The chemical components produced by P_2O_5, CaO, and SO_3. The presence of P_2O_5 is because the scale was formed in 40% phosphoric acid solution. Then, the large content of CaO and SO_3 proves that the crust formed is calcium sulphate ($CaSO_4$) crust. The formation of $CaSO_4$ scale is shown in the following reaction [24]:

$$CaO + SO_3 \rightarrow CaSO_4 \quad (1)$$

The table also shows the difference in the amount of CaO and SO_3 content using inhibitors and without using inhibitors. In the research using ATMP inhibitor, the CaO contained in the crust was 32% while that without using inhibitor was 35%. While the SO_3 content in the crust in the research using the inhibitor was 27.75% and the research without using the inhibitor was 28.6%. These results show that the research using ATMP inhibitor is less than the one without inhibitor. These results also prove that the ATMP inhibitor successfully reduced the CaO and SO_3 content in the scale. The percentages of CaO and SO_3 obtained were then calculated using the stoichiometric method to find the mass percent of the $CaSO_4$ crust. The results of the $CaSO_4$ scale calculation are shown in Table 2. below:

Table 2. Comparison Results of $CaSO_4$ Mass Fraction Using Inhibitor and Without Using Inhibitor

Mass Fraction $CaSO_4$ (%)	
Using Inhibitor	**Without Inhibitor**
75%	83%

In this research ATMP works to reduce scale. Table 4.2 shows that ATMP inhibitor can reduce the scale mass by 8%. This is because ATMP can inhibit the formation of calcium sulphate scale through its chelation and lattice distortion capabilities, which prevent scale formation. ATMP can also be used in mixture with other scale inhibitors to improve its inhibition performance [25]. The performance of ATMP in preventing scale formation is by binding Ca^{2+} ions present in $CaSO_4$ solution. This was shown by [26] with the following reaction:

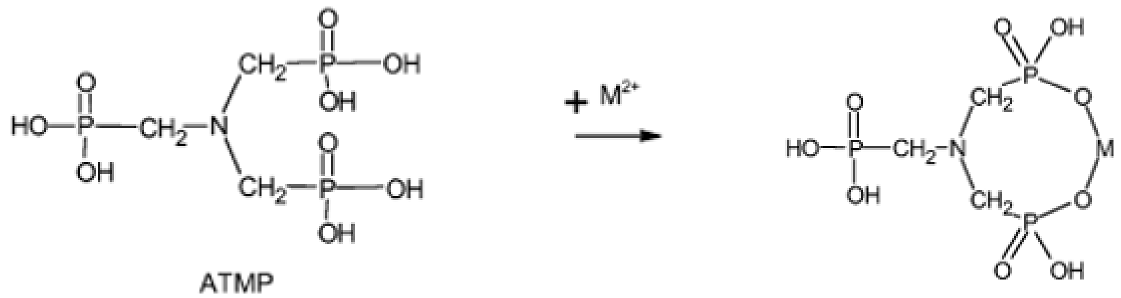


Fig. 14. The performance of ATMP in preventing scale

In the above reaction M is a divalent cation. In this research Ca^{2+} works as a divalent cation bound by ATMP as a scale inhibitor. This prevents the reaction between Ca^{2+} and SO_4^{2}, so that $CaSO_4$ scale does not form.

The addition of ATMP in this research did not reduce the quality of phosphoric acid. This is shown by the P_2O_5 content of 39.45% when using the inhibitor, which is greater than without using the inhibitor which is 35.65%. The increase in the percentage of the mass fraction is because ATMP can have an effect on increasing the phosphorus content of a substance [27].

Result and Discussion

The results indicate that the use of ATMP as an inhibitor effectively reduces the formation of $CaSO_4$ scale under the tested conditions. The observed minimum scale mass of 1.9 grams at an ATMP concentration of 9 ppm suggests that even low concentrations of this inhibitor can significantly reduce scale formation. This finding is consistent with previous [28], which reported similar reductions in scale formation when using phosphonate-based inhibitors.

Moreover, the XRF analysis showing an 8% decrease in $CaSO_4$ levels further supports the effectiveness of ATMP in mitigating scale formation. This reduction not only underscores the role of the inhibitor but also highlights its potential to improve operational efficiency in systems prone to scaling issues. Comparable studies [29] have documented similar efficacy with other inhibitors, suggesting that ATMP could be a viable option for industries dealing with scale deposits.

In conclusion, integrating ATMP inhibitors into water treatment processes could lead to significant improvements in efficiency and reduced maintenance costs associated with scaling problems.

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