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Determination ARIMA Model for the Discharge Acid Concentration in Pressure Oxidation Autoclave at A Gold Processing Plant

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Abstract: During industrial production, many quality parameters of products are measured to evaluate the quality of final products. These investigations are also applied for the machine parameters to control if they work properly. A huge amount of data is collected, recorded, and evaluated for these aims. Time series analyses are often a useful tool to evaluate the industrial data to analyze the products quality parameters or machine performances. The autoregressive integrated moving average (ARIMA) time series models are the most known and used method. One of the most important advantages of ARIMA models is its capability of near future estimation for the monitored process variable. For this aim, current research is carried out at a gold processing plant data. The plant gains the gold by applying the modern pressure oxide leaching in autoclave and cyanide leaching. Since the gold ore characteristics can be changed even, they are mined in the same mining area, monitoring the product quality and machine performances during production stages are needed. In this research, the data set, which was recorded at equal sampling time intervals and obtained in a month, is supplied from a gold processing plant in Turkey. During the gold production, the ground gold ore is subjected to the desulphurization process by pressure oxide (POX) in the autoclave. Discharge acid concentration is critical in this process and it is followed regularly by taking samples in 2 hours' time intervals in 24 hours. Using discharge acid concentration data set, the ARIMA (1,0,1) time series model was determined to monitor it. Also, near-future values of acid concentration were estimated by the ARIMA (1,0,1) model and compared with the real discharge acid concentrations. It was determined that there was a very good agreement between the estimated values obtained by the ARIMA (1,0,1) model and real values.

Keywords: Time series, ARIMA (1,0,1) model, Gold processing, Pressure oxidation, Acid concentration

Introduction

As of 2019, it is estimated that 197,596 tons of gold have been mined throughout history. Two thirds of this amount have been produced after 1950 (World Gold Council, 2021). In Turkey, gold production started in 2001 and the number of plants that started operating until 2020 was 18. Gold production, which started with 1.4 tons, reached 42 tons in 2020 and the total production reached 382 tons in 20 years (Altın Madencileri Derneği, 2021). As of 2019, Turkey has imported a total of 3215 tons of gold in the last 20 years. Turkey's gold reserve is 1500 tons and gold potential is 4618 tons (Altın Madencileri Derneği, 2021).

Despite the increasing gold production, Turkey ranks 5th among the countries that import the most gold in the world. Turkey's gold import, which was around 156 tons/year in last 20 years, reached 324 tons in 2018 (M. E.

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N. R., 2021). It is clear that Turkey, which is an important gold importer, will make great contributions to the country's economy in many aspects if it evaluates its current gold reserves.

The properties that determine the selection and effectiveness of the gold recovery process are ore grade, mineralogy, determination of gold-bearing minerals, grain size distribution of gold, grain size distribution of main and gangue minerals, mineral metamorphoses, liberation properties of gold minerals, form of gold in the ore (Şen, 2007). In the enrichment of gold ores, while gravity, amalgamation and agglomeration methods are used for coarse-grained gold-bearing ores, for fine-grained and low-grade ores flotation and hydrometallurgical methods can be used (Bhappu, 1990). In general, if the gold particles are microscopically dispersed, solution technology is used with the of cyanide. Over 120 years, cyanidation technology has been used in 84% of the world's gold production. (Bhappu, 1990).

In the acidic environment under high pressure and temperature where oxygen is used as oxidizer, the sulphide minerals that make up the refractory ores can be separated. This process is carried out in specially designed reactors called as autoclave (Marsden et. a., 2006). This process is not applied to whole ores, it is a pre-concentration stage prior to cyanidation. At this stage, gold grains found in the inclusions are liberated, sulfide minerals are oxidized and the ore is made suitable for cyanide leaching (Rusanen et. al, 2013).

In literature, investigations of time series in gold production were mainly application for gold price forecasting. Many researchers have been successfully forecasted the gold price by using ARIMA models (Triphaty, 2017; Davis et al., 2014; Guha et. al., 2016; Sharma et. al., 2015; Khan, 2013; Ali et. al., 2016). However, there is any academic research of ARIMA models on the gold processing plant to forecast any parameters. In this research, the data of discharge acid concentration of POX autoclave were used to test if ARIMA time series models could be used as a useful tool for forecasting the discharged acid concentration

Method

In this study, we used discharged acid concentration data of a pressure oxidation (POX) autoclave at a gold processing plant in Turkey. General flowsheet of the gold processing plant is given in Figure 1. At this gold processing plant, the ground ore is subjected to desulphurization process by POX in the autoclave since the main gang mineral of ore is pyrite (FeS2) which is an iron sulphur mineral. The purpose of the autoclave and pressure oxidation (POX) operation in gold processing is to pretreat the gold ore to prepare it suitable for cyanidation. Sulphide minerals contain fine-grained gold particles. Oxidation of sulphide minerals, mostly pyrite to sulphates and oxides releases gold particles. Then using cyanide, gold is extracted into a solution in the downstream circuit. Therefore, the sulphur is oxidized by a pressure autoclave prior to cyanide tank leaching (Figure 1). Discharge acid concentration is critical in this process and this is controlled regularly by taking samples in 2 hours' time intervals (12 samples are taken and analyzed for acid concentration in 24 hours).

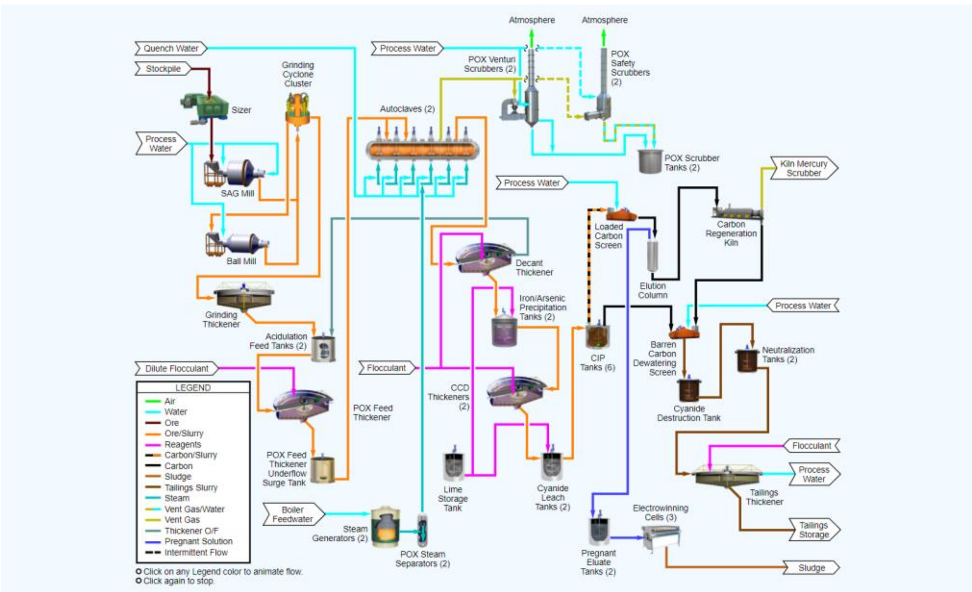

Figure 1. General flowsheet of gold processing plant

In order to evaluate the time dependent acid concentration data, totally 337 measured discharged acid data of POX circuit were obtained and used. Properties and ARIMA time series modelling studies of the data were carried out by using trial versions of Minitab 16.0 and Statgraphics XV softwares.

ARIMA (p,d,q) Time Series Model

There are many published textbooks available in the literature for time series analysis methods and models (Box et. al., 1976, Montgomery et al., 2008; Montgomery et. al., 2011). The readers can find detailed information in these books and the references cited in there. In short, time series analysis is used when observations are over 50 and they are obtained from equally spaced data periods (Datajobs, 2021). Time series analysis is used to forecast future patterns of events or to compare series of different kinds of events. The ARIMA, which is an acronym of **A**uto **R**egressive, **I**ntegrated, **M**oving **A**verage, model of a time series model is defined by three terms (*p*,*d*,*q*). The models are written as ARIMA(*p*,*d*,*q*). Identification of a time series is the process of finding values of *p, d* and *q*. The *p, d* and *q* describe the autoregressive (AR) part, integrated part (I) and moving average (MA) part of ARIMA models respectively. The *AR* denotes the function between current observation and previous observations, *I* represent if the investigated data values are used directly or they need to be differenced, *MA* explains if the current data depends the previous' error.

Autocorrelation and Determination of ARIMA Time Series Model

The correlation between consequence measurements (current observations of X_t and the observation from *p* periods before the current one, X_{t-p}) is defined as autocorrelation (Montgomery et al., 2008). The autocorrelation at given lag of *k* is calculated from the following formula:

$$r_k = \frac{\sum_{t=k+1}^{n}(y_t - \bar{y})(y_{t-k} - \bar{y})}{\sum_{t=1}^{n}(y_t - \bar{y})^2} \quad (1)$$

Results and Discussion

Data Properties of Discharged Acid Data

The normal probability plot with Anderson Darling (AD) normality test results (goodness of fit) is presented in Figure 2. As seen *p* value of test is 0,519 (>0,05) with AD value of 0,327. This result indicates that the data obey the normal distribution very well and there is no need any transformation. The mean value of 337 data is 21.82 g/L with standard deviation of 3,365.

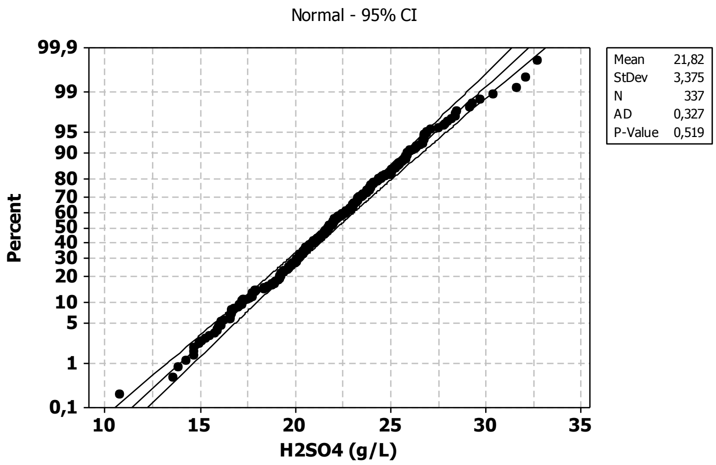

Figure 2. Probability plot of discharged acid concentration of POX

Time series plot in Figure 3 shows that the data used is stationary over time. This means that the data are not need to be differenced. Therefore, the integrated part (*d*) of ARIMA*(p,d,q*) model is 0 for the discharged acid concentration of POX autoclave.

Figure 4 gives the correlation relationship between the current observation (T) and the previous observation (t-1) at lag 1 for the acid concentration data. It seen clearly that consequent data observations of acid concentrations have an important correlation. They show symmetrical distribution around 1:1 line.

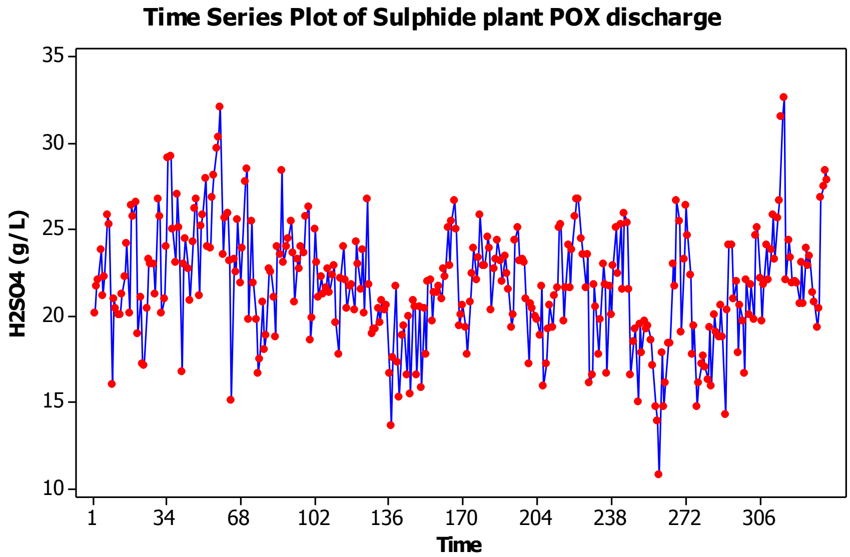

Figure 3. Time series plot of POX's discharged acid concentration

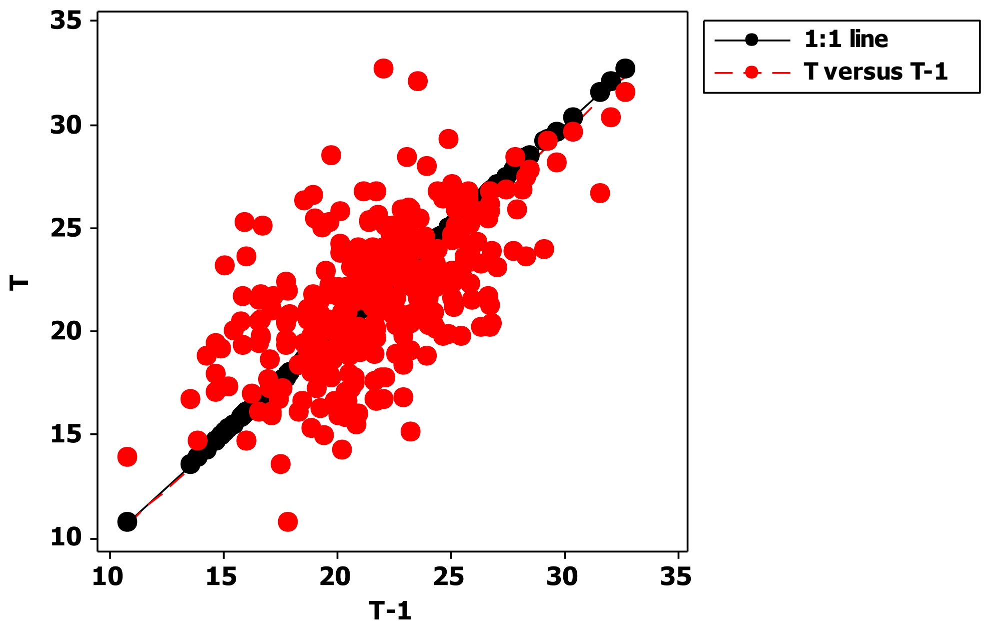

Figure 4. Scatter plot for *T* and *T-1*

In Figure 5, the autocorrelation function (ACF) and the partial autocorrelation (PACF) plots are presented. As seen, ACF decays quickly for the first five lags then almost constant within the 95% confidence limits and only one important spike exists in the first lag of PACF plot then decays immediately. This means that autocorrelation is explained efficiently by lag 1 autocorrelation. As shown in ACF plot, it was determined that coefficients of acid concentrations at lag 1 have a value of 0,585 and it is equal to 0,419 at lag 2.

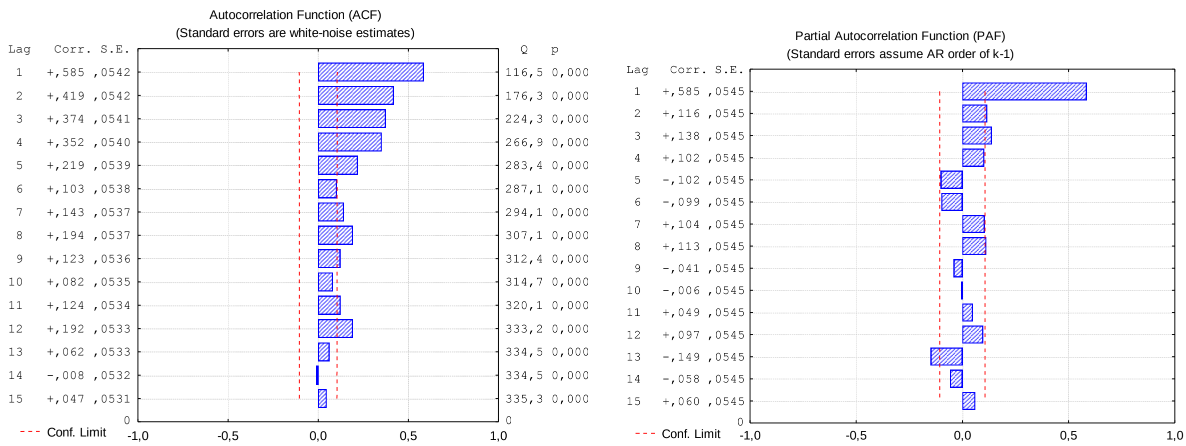

Figure 5. ACF and PACF plots for 15 lags of POX's discharge acid concentration

Table 1 compares the results of fitting some possible ARIMA time series models to the POX's discharged acid concentration data. Between the models, the model with the lowest value of the Akaike Information Criterion (*AIC*) is the ARIMA (1,0,1) model. Therefore, this model was chosen to generate the forecasts of discharged acid concentration.

Table 1. ARIMA models for the POX's acid discharge data

Model	*AIC*
ARIMA(1,0,1) with constant	2,005
ARIMA(1,0,2) with constant	2,00621
(ARIMA(1,1,2)	2,01398
ARIMA(2,0,2) with constant	2,01459
ARIMA(2,0,0) with constant	2,01672

The output presented in Table 2 summarizes the statistical significance of the ARIMA (1,0,1) model terms in the forecasting. ARIMA (1,0,1) model with constant, or ARMA(1,1)model, is described as following Equation 2 (Castagliola et. al., 2005):

$$X_t = \delta + \emptyset X_{t-1} + \theta a_{t-1} + a_t \tag{2)}$$

Here; δ is the constant of the model, $\emptyset$ is the constant of autoregressive (AR) term of the model, θ is the constant of moving average (MA) of the model, a_t is the error term, normal random shock (white noise) at time *t*. White noise is assumed to be independent and identically distributed normal (0, σ_a^2), σ_a^2 is the variance random noise (white noise variation).

In ARIMA (1,0,1) model, the AR (1) constant, i.e. δ, is equal to μ (1- $\emptyset$). Then it is equal to 21,8699*(1-0,793677) = 4,51226 (Table 2).

Terms with *p*-values less than 0,05 are statistically significantly different from zero at the 95,0% confidence level. The *p*-value for the AR (1) term is less than 0,05, so it is significantly different from 0. The *p*-value for the MA (1) term is less than 0,05, so it is significantly different from 0. The *p*-value for the constant term is less than 0,05, so it is significantly different from 0. The estimated standard deviation of the input white noise (σ_a) equals 2,70106.

Table 2. ARIMA (1,0,1) model summary

Parameter	*Estimate*	*Stnd. Error*	*t*	*P-value*
AR(1), $\emptyset$	0,793677	0,0559039	14,1972	0,000000
MA(1), θ	0,325924	0,0845613	3,85429	0,000139
Mean, μ	21,8699	0,469544	46,5769	0,000000
Constant, δ	4,51226			
White Noise Variance (σ_a^2)	7,29572			
White Noise Std. Dev. (σ_a)	2,70106			

The final time series equation obtained from the ARIMA(1,0,1) model is given in the following.

$$X_t = 4{,}51226 + 0{,}7937X_{t-1} + 0{,}3259\,a_{t-1} + a_t \qquad (2)$$

a_t: Random noise or white noise at time =1, 2,…. which has a mean of zero (0) and standard deviation of σ_a i.e., $N(0; 2{,}70106)$

The diagnostic check results of ARIMA (1,0,1) model is given in Figure 6. The ACF plots of residuals (the difference between actual and estimated acid concentrations) shows that, the residuals are not autocorrelated (autocorrelation at lag 1 eliminated). In the right plot of Figure 5, the ARIMA (1,0,1) model residuals are distributed normally, has a mean of zero (0). The residuals are distributed homogeneously around zero, showing the adequacy of the model.

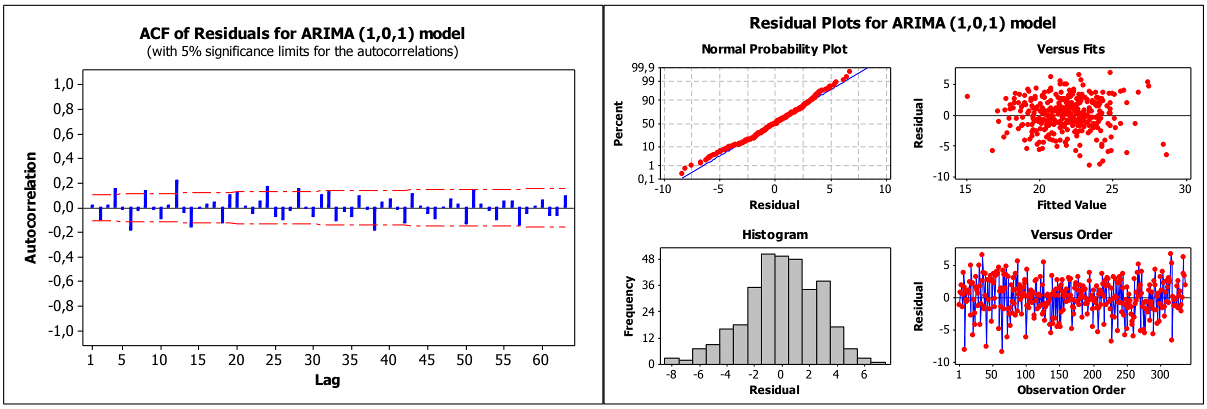

Figure 6. ACF of residuals and residual plots for fitted ARIMA (1,0,1) model

In Figure 7, the actual and estimated acid concentrations by Equation 2 are given in the same plot. It seems that the forecasting model of ARIMA (1,0,1) model has a high accuracy to estimating the discharges acid concentration of POX autoclave in gold processing plant.

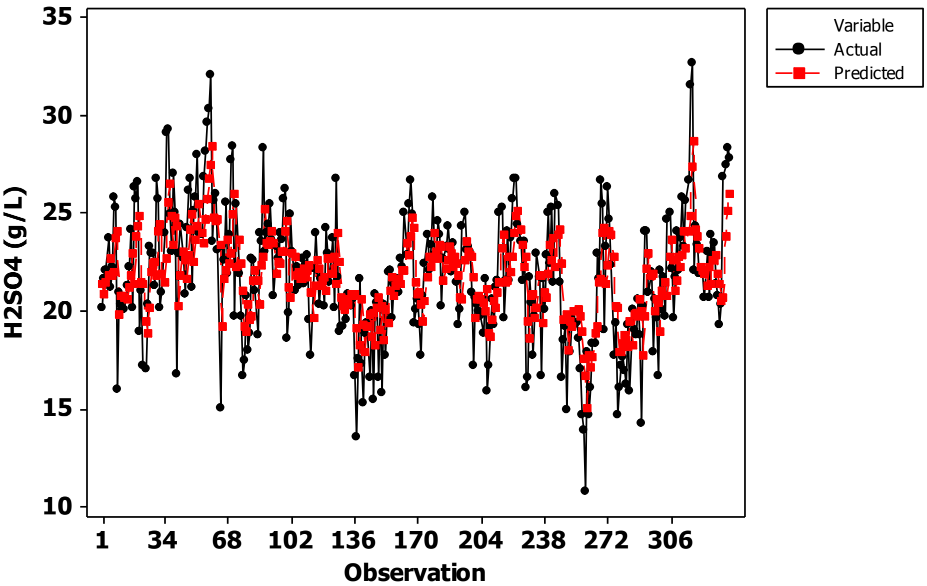

Figure 7. Actual versus predicted plot

Using the historical data, time series forecasting for near future observations can be done. For this aim, the performance of ARIMA (1,0,1) model was tested to forecast real data of the last 24 hours acid concentrations (measurements of 326-337 data). Actual and model fitted values are plotted within the 95% confidence limits and is presented in Figure 8. The ARIMA (1,0,1) model gives very good forecasting performance since all the actual data values forecasted are within the 95% confidence limits.

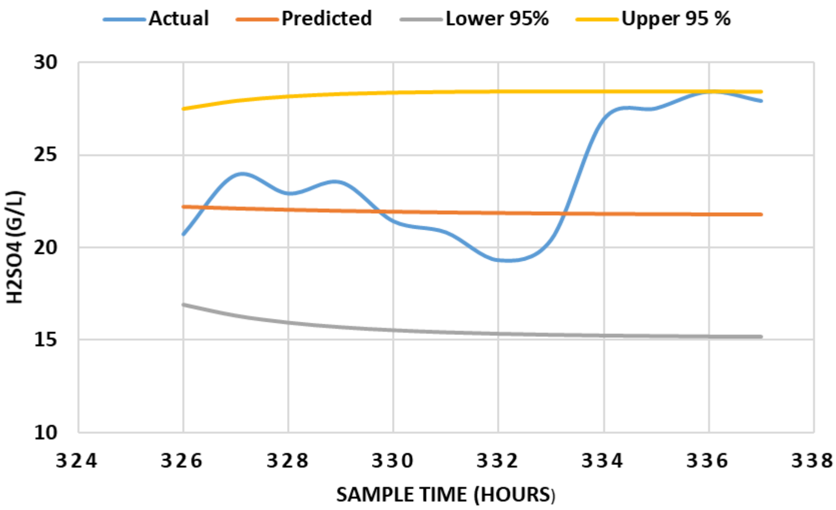

Figure 8. Actual versus predicted acid concentration of POX discharge for the last 12 hours by ARIMA (1,0,1) model

Figure 9 shows the near future forecasting of acid concentrations of POX autoclave for the next 24 hours (338-349 data).

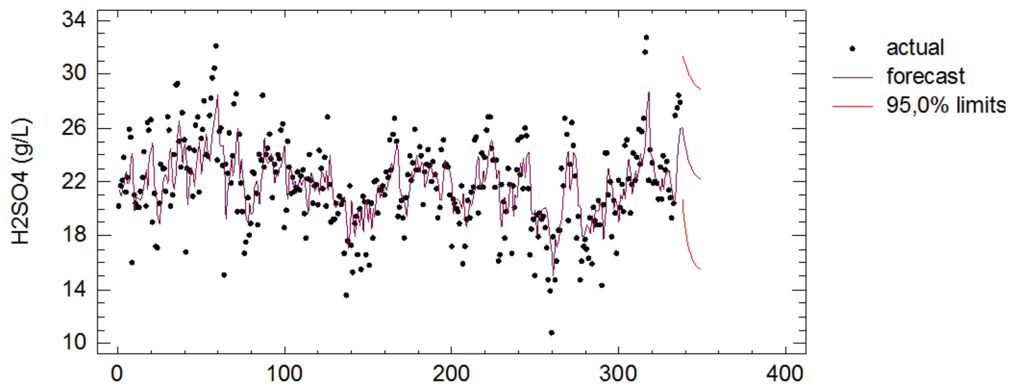

Figure 9. Actual points and forecasted discharge acid concentration. Near future estimation with 95% limits for the next 24 hours

Conclusion

In a gold processing plat, many critical parameters in different production stages should be controlled to reach a high production recovery. The parameter of discharged acid concentration from POX autoclave device is only one of these parameters. The results of this investigation indicate that forecasting is possible for discharge acid concentration by using historical data. It was determined that these data have important autocorrelation. This research showed that ARIMA (1,0,1) model can be used conveniently for forecasting the discharge acid concentration of POX autoclave in a gold processing plant. When the statistical process control (SPC) method is applied to control of quality parameter if the process is under control or not, the important autocorrelation determined in this study should be taken into account. Since wrong uncontrolled points are detected and the process control are interpreted wrong, the autocorrelation assumptions should be verified in SPC applications.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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