PREDICTION OF ASH CONTENT FOR COARSE CLEAN COAL PREPARED WITH HEAVY MEDIUM DRUM BY ARIMA(1,0,1) MODEL

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Abstract: The aim of this research is to model the ash content of +18 mm clean coal product obtained by a heavy medium drum at Dereköy coal preparation plant in Turkey by a time series model. The drum was operated 355 days in 2010 and its one year of daily as-received ash content data of +18 mm clean coal was used for evaluation by an ARIMA time series model. The ash data was found non-normal distribution and to fit log-normal distribution well. The ARIMA(1,0,1) time series model determined for the log-transformed data was the best model to represent the ash content of +18 mm coal. This model was shown to be used conveniently within the 95% confidence interval for estimating the ash contents that will be produced in short time period.

Keywords: Coal preparation, heavy medium drum, ash content, lognormal distribution, ARIMA(1,0,1) model

Introduction

Coal is one of the most important energy sources in the world. Turkey has about 12.88 billion tons of coal reserves (Özbayoğlu, 2013). The 11.56 billion tons of these reserves are low quality lignite and the rest is bituminous coals (Özbayoğlu, 2013). Prior to usage of coals, it is necessary to remove some constituents which cause problems during their combustion process in terms of recovery and environmental aspects. This is done by applying coal preparation techniques. Coal washing is the most important method to improve coal quality. In general, coals are washed by using density differences between coal and ash bearing constituents. Depending on the particle size of coals, heavy medium drums and vessels are used for the coarsest coals, heavy dense cyclones are used for relatively fine coals and spirals are used for the fine coals treatment.

During the desired quality coal production, it is necessary to estimate the coal quality for near future and hence to model the coal quality data obtained. The data structures in nature obtained from mineral processing are suitable for time series modeling since data characteristics are random and probabilistic (Ketata and Rockwell, 2008; Ganguli & Tingling, 2001) and these continuous processes can be considered discrete processes (Trybalski & Cieply, 2000). Some examples of time series model applications on coal production have existed in the literature (Cheng, et. al., 1982; Ganguli & Tingling, 2001; Gleit, 1985; Huang, et., al., 2002; Taşdemir, 2012; Taşdemir, 2013; Taşdemir, 2016a and 2016b).

In this research, ash content data obtained from heavy dense drum device at Dereköy coal washing plant in Soma, Turkey were used. Previous studies that carried out for Dereköy coal preparation plant showed that ash content of coals could be modelled successfully by ARIMA(1,0,2) model for -0.5+0.1 mm clean coal product of spiral (Taşdemir, 2013), ARIMA(2,0,0) or AR(2) model for the -18+10 mm and -10+0.5 mm clean coal products of the first heavy dense cyclone (Taşdemir, 2016a and 2016b). In addition, moisture content and ash contents of -18+0.5 mm middling product of second heavy dense cyclone have been found to be modelled by ARIMA(1,0,1) and ARIMA(0,1,2) time series model respectively at Tunçbilek coal washing plant in Turkey (Taşdemir, 2012).

Since, there is no information about time series models in literature that can be used for the estimation of ash content for the coals prepared with heavy medium drums, this research aims to model ash content data of clean coarse coals produced by a heavy medium drum at Dereköy coal preparation plant. By using one year ash content data of +18 mm clean coals prepared by heavy media drum, the most suitable time series model that can be used for the prediction of ash content have been determined and actual ash contents are compared with ash contents predicted by ARIMA model.

Materials and Methods

Daily ash content of +18 mm coarse clean coals were obtained from Dereköy coal preparation plant in Soma, Turkey. The ash content data belong to 2010 year. Simplified flowheet of plant is presented in Figure 1. This flowsheet is modified from Şengül (2008). As seen, particle size of run of mine coals is first reduced to -150 mm and then screened by 18 mm sieve. The +18 mm fraction is washed by a heavy medium drum with two compartments. The cleanest coals are produced in the first compartment of drum and the materials which are sunk in the first compartment are send to second compartment to obtain middling and shale products. In this research, the ash content of +18 mm clean coal data was used. Sample point of this product is shown as star symbol in Fig. 1. The data 355 ash content data in total were used in this work.

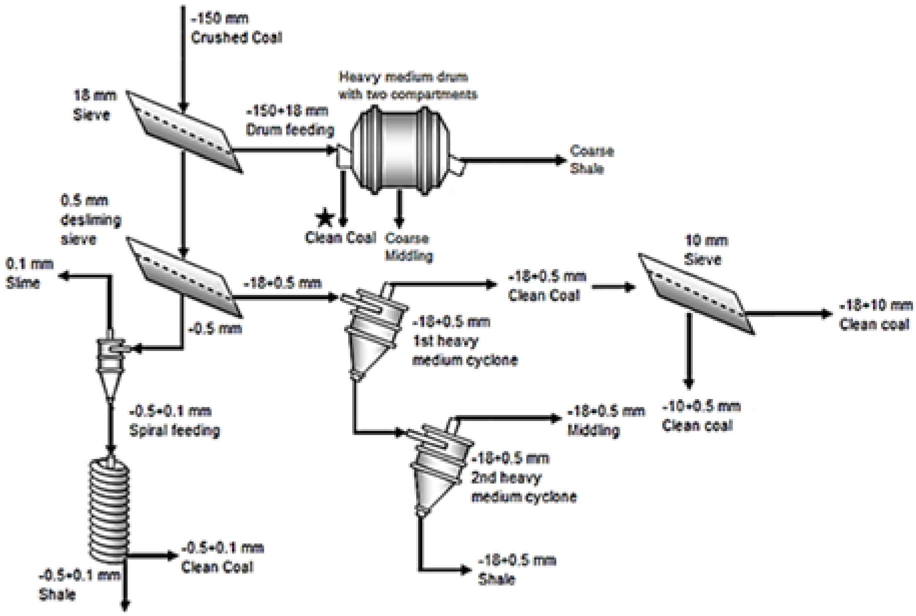

Figure 1. Flowsheet of Dereköy coal washing plant showing +18 mm coarse clean coal product of heavy medium drum which is shown as a star symbol. Modified from Şengül (2008).

The ash content data were evaluated by ARIMA(p,d,q) time series models. The model which gave the lowest AIC (Akaike information criterion) was chosen as the best describing time series model for the +18 mm clean coals. Many published books exist about data analysis by ARIMA models. Detailed information about ARIMA time series models and model selection methods can be found in books of Montgomery et al., (2008) and Montgomery & Runger (2011) therefore more information will not be presented again in detail here. Trial versions of Statgraphics XV and Minitab 16.0 software were used for determining of data properties and time series model.

Results and Discussion

Data Properties of +18 mm Ash Content Data

Summary of ash content of +18 mm data is given in Table 1.As seen in Table 1, average of one year ash content data produced by heavy dense drum is 12.85 with a standard deviation of 1.90. The standardized skewness and standardized kurtosis values can be used to determine whether the sample comes from a normal distribution. For a normal distribution, values of these statistics should be inside the range of -2 to +2. Standard skewness and kurtosis values of +18 mm coal ash content were 7.89 and 13.99 respectively. These results indicate that ash content data departure from normality significantly.

Table 1: Summary Statistics for the ash content of +18 mm clean coal

Count	355
Average	12.85
Standard deviation	1.90
Coeff. Of variation	14.78%
Minimum	8.41
Maximum	23.72
Range	15.31
Stnd. skewness	7.89
Stnd. kurtosis	13.99

Box-Whisker and histogram plots for +18 mm ash content are given in Fig. 2. These plots show that the data have important outliers

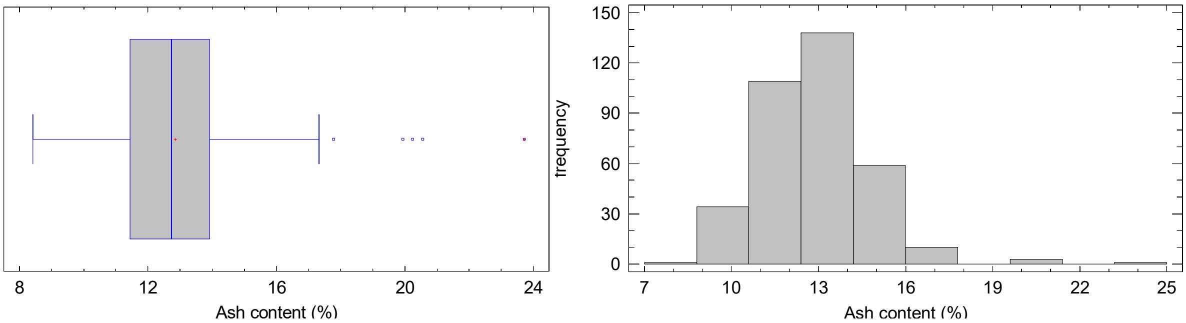

Figure 2. Box-Whisker and histogram plots for +18 mm ash content

Normal probability and symmetry plots of ash content are presented in Fig. 3. Whole plots in Fig. 2 and Fig. 3 support the information in Table 1. As seen in Box-Whisker plot in Fig. 2, there are many outliers and it can easily skew normally distributed data. This may be the reason for non-normality distribution of ash content data. Both normal probability plot and symmetry plots in Fig. 3 support this. The ash content data skewed to right (Fig. 3b) and Anderson-Darling (AD) test confirm non-normality since *p* value of AD test is <0.005 (Fig. 3a).

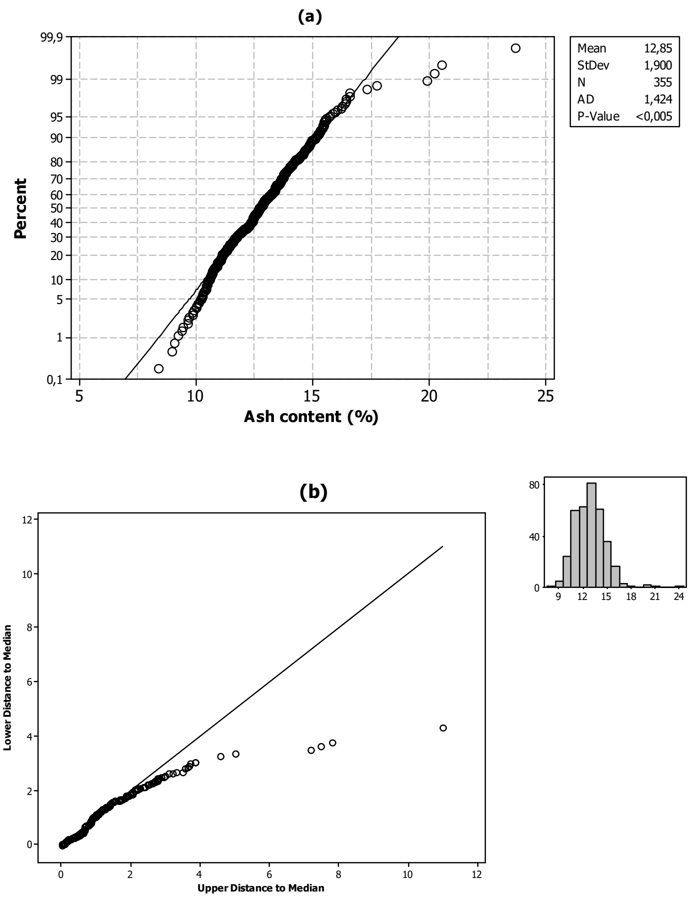

Figure 3. Normal probability (a) and symmetry (b) plots for +18 mm ash content

The ash content data were tested by some distribution functions and transformation methods. The probability plots of results obtained are given and compared with normal distribution plot and Anderson Darling (AD) test results in Fig. 4. Lognormal distribution, Box-Cox and Johnson transformation have *p* values higher than 0.05 (Figs. 4b, 4c and 4d). However, both lognormal distribution (Fig.4c) and Johnson transformation (Fig.4d) have the same *p* values of 0.176 and give better results than Box-Cox transformation (Fig.4b). In this research, lognormal distribution was chosen since it is more simple transformation method than Johnson transformation.

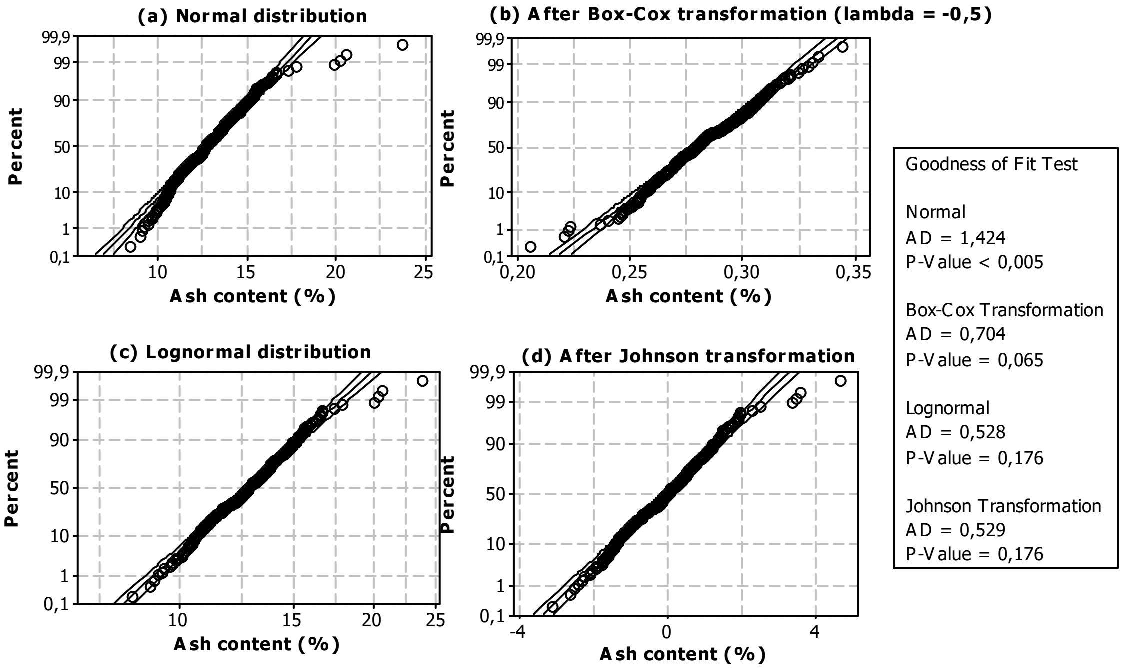

Figure 4. Probability plots for +18 mm clean coal with 95% confidence interval

Time Series Analysis of Ash Data

Time series plots of original and log transformed ash content data are comparatively presented in Fig. 5a and 5b respectively. Since original ash data do not obey normal distribution, log transformed ash content data in Fig. 5b will be considered during the determination of ARIMA(*p,d,q*) time series model. As seen the data are stationary indicating that there is no need to take any difference to make data stationary. Therefore, the *d* value is zero (0) in the ARIMA(*p,d,q*) model, i.e. the model will be ARIMA(*p,0,q*).

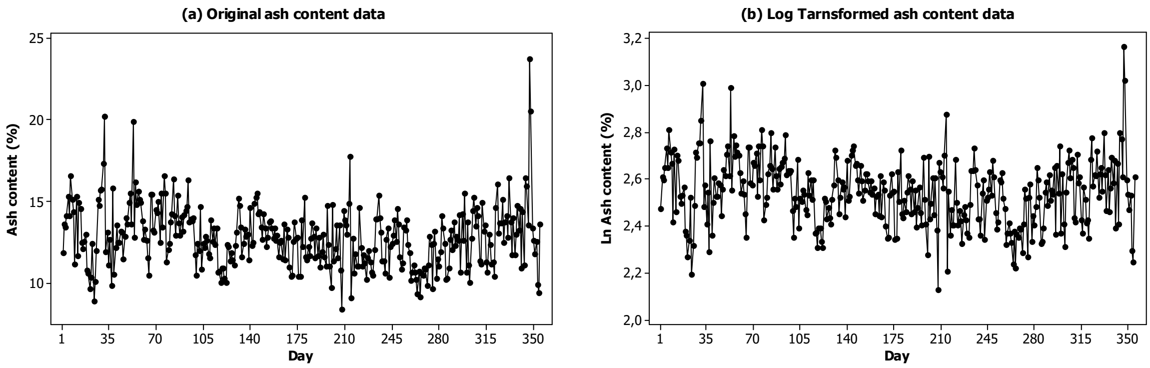

Figure 5. Time series plots of original (a) and log transformed (b) ash content data

Fig. 6 show scatter plot presenting the possible correlation of current log transformed ash data value (*T*) with its previous log transformed ash data (*T-1*). As seen clearly, there is a considerable correlation between two consequent ash data values. In order to determine the correlation degree, autocorrelation function (ACF) and partial autocorrelation function (PACF) plots were generated for 60 lags. The results of ACF and PACF plots with 5% significance level are shown in Fig. 7a and 7b respectively. According to PACF plot in Fig 7a, autocorrelation decays after few lags and then remains 95% confidence limits indicating the data stationary as determined previously. Fig. 7b shows that the ash content data have one important autocorrelation at first lag and then at the second lag. We estimated autocorrelation coefficients of ash content data at first lag is 0.388 and second lag is 0.325 (Fig. 7a). These results indicate that ash content data have considerable autocorrelation and should be taken into account.

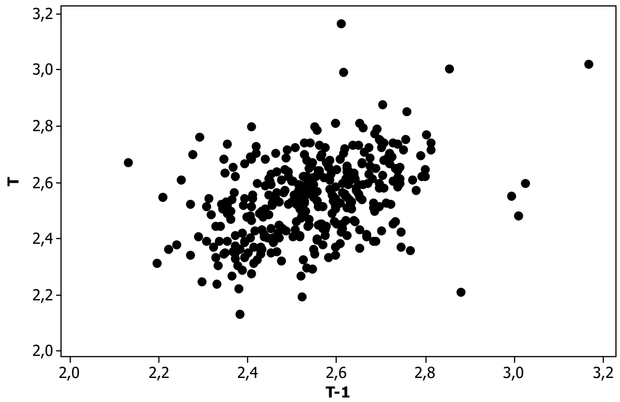

Figure 6. Scatter plot of ash content data, *T* versus *T-1*

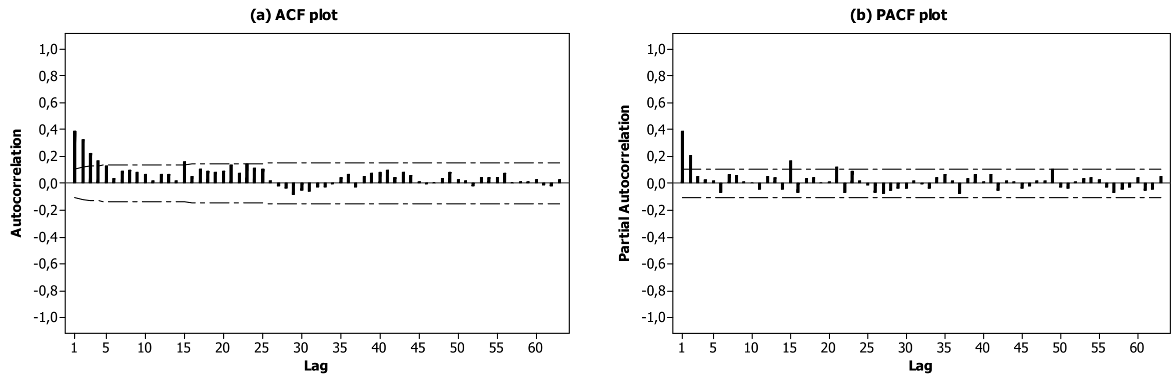

Figure 7. Autocorrelation function (ACF) (a) and partial autocorrelation function (PACF) (b) plots of log transformed ash content data with 5% significance limits

Table 2 compares the results of fitting different time models to the ash content of +18 mm clean coal data. As seen in Table 2, ARIMA(1,0,1) model is the lowest value of the Akaike Information Criterion (AIC), therefore it has been selected to generate the ash content forecasts. Parameters of ARIMA(1,0,1) model is shown in Table 3. Table 3 summarizes the statistical significance of the terms in the forecasting model of ARIMA(1,0,1). Terms with *p* values less than 0.05 are statistically significantly important at the 95% confidence level. The *p* values for the AR(1), MA(1) and mean terms were found less than 0.05, all of them are significantly different from 0 (Table 3). The estimated standard deviation of the input white noise equals 0.1289.

Table 2: Time series model comparisons for ash content estimation

Models	*RMSE**	*AIC*
ARIMA(1,0,1)	0.129306	-4.07425
ARIMA(2,0,0)	0.129393	-4.07289
ARIMA(2,1,1)	0.129451	-4.072
ARIMA(1,1,2)	0.129592	-4.06983
ARIMA(2,0,1)	0.129366	-4.06769

**: Root Mean Squared Error*

Table 3: ARIMA(1,0,1) Model summary

Parameter	*Estimate*	*Stnd. Error*	*t*	*p value*
AR(1)	0.768799	0.074445	10.3271	0.000000
MA(1)	0.46089	0.102183	4.51042	0.000009
Mean, μ_0	2.54279	0.015762	161.324	0.000000
Constant, δ	0.587895			

Estimated white noise variance (σ_a^2)= 0.0166; Estimated white noise standard deviation (σ_a)= 0.1289

For a good time series model, the residuals should be independent and identically distributed (*i.i.d*). To determine these properties, diagnostic tests were carried out whether the residuals of the model obey normal distribution and have no autocorrelation to determine the model adequacy for the ash content data. Fig. 8 shows the normal probability ARIMA(1,0,1) model residuals. The model residuals fit the normal distribution very well according to the AD normality test result (*p*=0.640) (Fig. 8). Residuals were also controlled for the autocorrelation. The generated ACF and PACF plots for the model residuals within the 5% significance limits are presented in Fig. 9a and 9b respectively. As seen clearly, the autocorrelations are within the 95% confidence intervals suggesting that there are no autocorrelations between consecutive residual values. All these results indicate that the ARIMA(1,0,1) model is adequate enough to forecast ash content of +18 mm coals obtained by heavy dense drum.

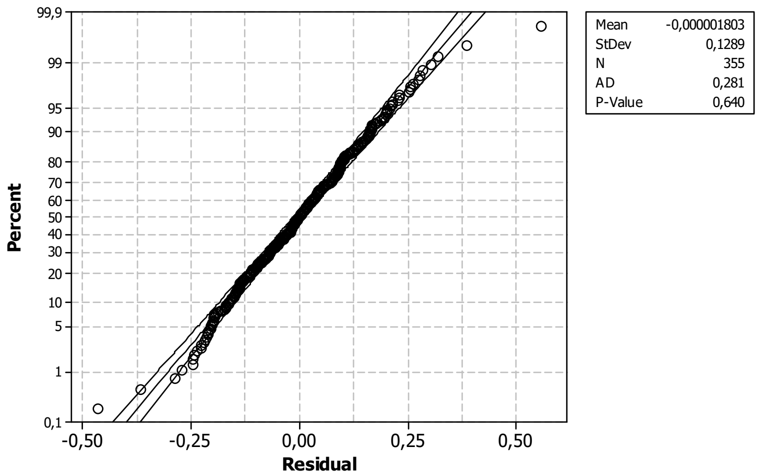

Figure 8. Residual normal probability plot of ARIMA(1,0,1) model for log transformed ash data

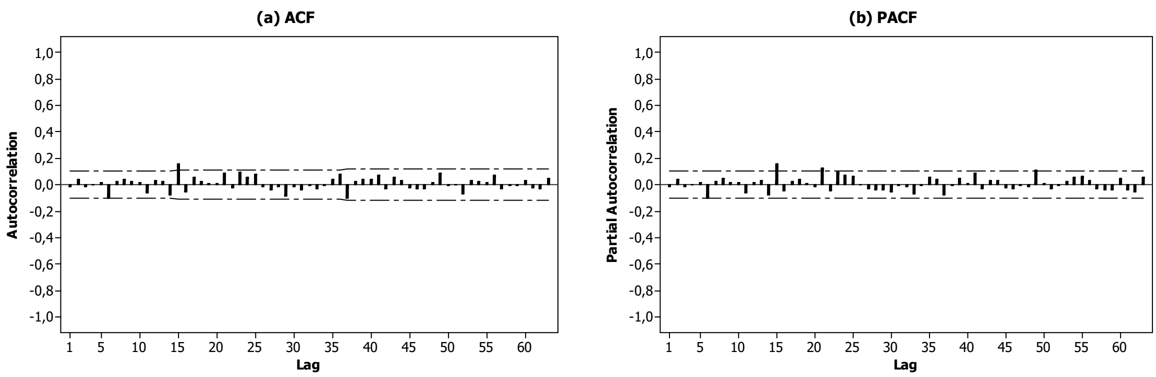

Figure 9. Autocorrelation function (ACF) (a) and partial autocorrelation function (PACF) (b) plots of residuals for ARIMA(1,0,1) model with 5% significance limits

As stated above, the ash content of +18 mm clean coal produced by heavy medium drum, X_t, can be modelled by ARIMA(1,0,1) or ARMA(1,1) model well. General description of ARIMA (1,0,1) model is (Castagliola and Tsung, 2005):

$$X_t = (1-\phi)\mu_0 + \phi X_{t-1} + \theta a_{t-1} + a_t \qquad (1)$$

Where X_t is the observation at time t=1, 2, ,…, a_t is the random noise or white noise at time =1, 2, ,… which is assumed to have mean of zero (0) and standard deviation of σ_a, ϕ is the autoregressive parameter of the model which corresponds to p term in the model, θ is moving average parameter which corresponds to q term in the model and μ_0 is the nominal mean of the process and δ is the constant calculated from μ_0(1- ϕ), (Castagliola and Tsung, 2005).

The ash content data can be modelled by applying ARIMA(1,0,1) process with $\mu_0 = 2.5428$, $\phi = 0.7688$, $\theta = 0.4609$, where the a_t have a normal distribution with mean of zero and $\sigma_a = 0.1289$. Therefore, the ARIMA(1,0,1) time series model that can be used for the ash content of +18 mm clean coal produced by heavy medium drum is:

$$X_t = 0.5879 + 0.7688X_{t-1} + 0.4609a_{t-1} + a_t \quad (2)$$

Where, X_t is the log transformed ash value at time, a_t is the random noise which have distribution of N(0, 0.1289). Fig. 10 shows the actual and forecasted log transformed ash contents by ARIMA(1,0,1) model (Eq. 2). There are good agreement between the actual and forecasted ash content values in Fig. 10. This result indicates that ARIMA(1,0,1) model determined is adequate enough for the near future prediction of ash content.

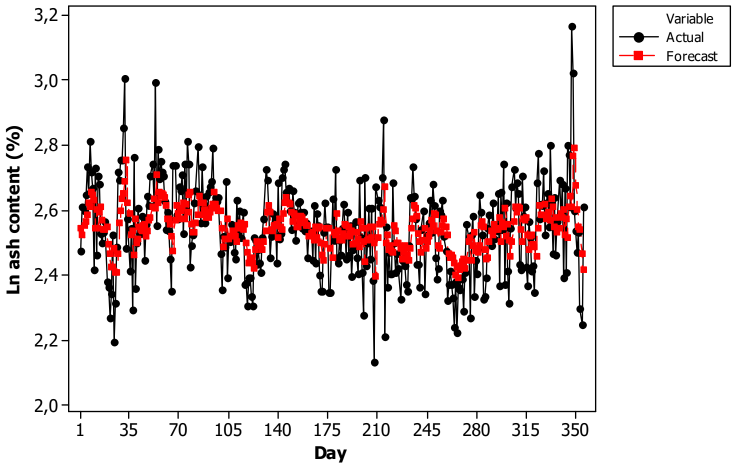

Figure 10. Actual Ln ash content versus forecasted ash content by ARIMA(1,0,1) time series model

Conclusion

Detailed examination of daily ash content of +18 mm clean coal product produced by heavy medium drum showed that ash content data obtained were not obey normal distribution due to the outliers. The ash content data were determined as skewed to the right. The normality can be achieved by both lognormal distribution and Johnson transformation. Since taking natural logarithm was easier than Johnson transformation, ARIMA time series model selection was applied log transformed ash values. No differencing operation was applied to ash data since the data were stationary with time. According to the AIC values of times series tested, the ARIMA(1,0,1) or ARMA(1,1) was determined the best time series model to forecast of ash content values for +18 mm clean coal product. The residuals of model have a distribution of $N(0, 0.1289)$ and no autocorrelation. Since the actual and forecasted ash values are good agreement, the ARIMA(1,0,1) model can be used conveniently for near future estimation of the ash content of +18 mm clean coal to be produced by heavy medium drum. It is suggested that time series models that can be used for the other quality characteristics of coal such as moisture, calorific value, sulphur content etc. can be developed to forecast them.

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