

## Statistical Analysis for Studying Autoclave Test

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**Abstract:** Late expansion may occur as a result of the hydration of calcium oxide and magnesium oxide in the hardened concrete which if exceeded, may cause a cracks. One of the modern methods used to estimate the stability of the cement size (expansion) is the autoclave method, this study aim to estimate the stability of the cement and this will gives an indication of the late expansion. The statistical program “Statistica” were used in the analysis of the factors affecting the results of autoclave test these factors were (CaO, SO<sub>3</sub>, MgO, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, free lime, LOI, IR, LSF). The linear regression method was used and the study were done in two ways individually and again in groups. The multiple linear regression was found to be very appropriate for predicting the autoclave expansion of Portland cement. On the other hand there is no significant variance in the value of correlation coefficient when studying the factors individually or in groups, so, it is preferable to use models with individual factors for facilitate of research.

**Key words:** Statistical analysis, autoclave expansion, MgO, CaO, soundness of cement, correlation coefficient

### INTRODUCTION

The presence of uncombined lime and magnesium oxide in the form of periclase in Portland cement production could cause unsoundness and that by a delayed very high expansion in cement-based constructions this could be explained by the formation of Ca(OH)<sub>2</sub> and Mg(OH)<sub>2</sub> due to the existence of (free CaO) and MgO in the mixture it is not clear yet how much is the amount of free CaO and MgO that could cause a damage in the cement-based constructions.

Gonnerman *et al.* (1953) they were working to determine the percentage of free CaO and MgO that could cause an excessive expansion and they found it about (1.4-2%) and (4-5%), respectively. Rehsi and Majumdar (1967) showed that beyond 5% of MgO, the volume expansion of cement rises aggressively.

According to Lea (1970) cement with total MgO content in the range of (1-2%) and free lime below (2%) will pass the autoclave test. However, cement with high percentage of MgO, the free CaO need to be below 1% to ensure its compliance.

Czermin (1980) found that cement containing MgO below (3.5%) could fail in soundness autoclave test. the differentiation in results are related to several factors such as cement fineness, cooling conditions, C<sub>3</sub>A content, alkalis, etc.

Huntzinger and Eatmon (2009) during cement hydration CaO in conjunction with SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> and this what gives the Portland cement its hardness due to the formation of calcium aluminosilicates and

aluminoferrite hydrate. Increasing the percentage of MgO (>2%) in the Portland cement may affect negatively the cement's soundness, especially, at late ages, a high percentage of SO<sub>3</sub> tends to cause unsoundness of cement. Americans in their standard, ASTM C618 limits SO<sub>3</sub> to 4 and 5% whilst the Indian standard limits SO<sub>3</sub> to 2.75%.

According to Anonymous (2005) the main factor controlling cement expansion is the CaO, MgO content due to the formation of Ca(OH)<sub>2</sub>, Mg(OH)<sub>2</sub> (in the last ions resulting from CaO, MgO, respectively). Chatterji (1995) showed that the mechanism of expansion of both oxides is similar but CaO is higher because it is more soluble than MgO.

Lea (2004) stated that the overlap between these two oxidants is what cause this expansion. It was found that the cement containing CaO by <2% will succeed in testing the water-solvent (autoclave) when the total MgO content is low (1-2%). However, in the high level of MgO, free CaO content is necessary to have a CaO concentration of <1% in order to be safe.

Neville (1995) noted that (the determinant in the selection of a autoclave) is affected by MgO, CaO and not affected by CaSO<sub>4</sub> in contrast to significant research by researchers who indicated that CaSO<sub>4</sub> affects the results of a autoclave. Latif (2001) suggested using the autoclave test to determine the optimum ratio of gypsum content added during clinker milling in the cement industry.

In addition to the chemical composition of the cement is a key factor affecting the expansion and the results of the analysis of the autoclave test. Lea (2004) explained

that the degree of stability of the cement depends on the size of the crystals as the small crystals dissolve more quickly and without the production of compressed internal pressure.

Chopra showed that the process of grinding the clinker containing a high percentage of MgO to a high degree of smoothness can be considered as an effective way for the production of fixed-size cement. Czernin (1980) found that by increasing the fineness of free CaO, the expansion decreases and became more regular. Essa statistically proved that LSF and LOI are of the factors that reduce the expansion of cement.

Borhan and Al-Rawi (2016) showed that there is a considerable effect of MgO content on autoclave expansion tests and on the optimum gypsum content in cement. The increase in MgO content results in an increase in the autoclave expansion and a reduction in the optimum gypsum content. The autoclave test is not sensitive to the variation in SO<sub>3</sub> content in cement at low MgO value. The sensitivity is increased with increase MgO content.

Al-Attar (2013) the model was tested with new raw data and the predictions were highly correlated to the experimental results ( $r = 0.92$ ), a t-test was carried out and it showed that there is no difference between means of experimental and predicted sets of values. The good predictions give the chance to make use of the model in saving time and money.

**Data collection:** Data were collected from various construction laboratories and it consists of (40) different cement samples taken from different Iraqi and foreign cement factories (29) of the samples were ordinary Portland cement while the other (11) samples were sulphate resisting Portland cement.

**Statistical analysis:** The statistical analysis implemented by using the statistical program (statistica) and the factors (as individuals) that studied in the present study were (MgO, CaO, SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, SO<sub>3</sub>, L.O.I, IR, L.S.F, IST, FST, free lime) and groups factors were (MgO CaO, MgO CaO Blane, MgO CaO SO<sub>3</sub>, MgO CaO SO<sub>3</sub> Blane). The statistical factors that used to evaluate the models in this research are as below with definition of each.

**Multiple R:** The coefficient of multiple correlation is the positive square root of R<sup>2</sup> (the coefficient of multiple determination). This statistical factor is useful in multivariate regression (i.e., multiple independent variables) when it is wanted to describe the relationship between the variables.

**R<sup>2</sup>:** This coefficient of multiple determination measures the reduction, in the total variation of the dependent variable due to the (multiple) independent variables:

$$R^2 = 1 - [\text{Residual SS} / \text{Total SS}]$$

Where:

Residual SS = The Error Sums of Square

Total SS = The total Sums of Square

The R<sup>2</sup> value is an indicator of how well the model fits the data, R<sup>2</sup> close to 1.0 indicates that it has accounted for almost all of the variability with the variables specified in the model.

**Adjusted R<sup>2</sup>:** The R<sup>2</sup> is adjusted by dividing the error sum of squares and total sums of square by their respective degrees of freedom:

$$\text{Adjusted } R^2 = 1 - [(\text{Residual SS}/\text{dfr}) / (\text{Total SS}/\text{dft})]$$

**SE of estimate:** This statistic coefficient measures the dispersion of the observed values about the regression line.”

**F-value:** The F-value is used as a test of the relationship between the dependent variable and the set of independent variables:

$$F = \text{Regression mean square} / \text{Residual mean square}$$

The range of difference (df) between the actual and predicted Autoclave expansion values was calculated for each model within confidence interval of 0.95. This means that there is a probability of 95% of difference between the actual and the predicted values falls within a range of  $\pm df$ , thus, the actual values equals to predicted values  $\pm df$ .”

## MATERIALS AND METHODS

**Independent variables:** The following variables are selected to be as the independent variables:

- The four main compounds of Portland cement (i.e., C<sub>3</sub>S, C<sub>2</sub>S, C<sub>3</sub>A and C<sub>4</sub>AF) which were calculated using Bogue's equations
- The fineness of cement (in terms of Blaine specific surface)
- Chemical analysis parameters (i.e. MgO, Free CaO, SO<sub>3</sub>, LOI, IR and LSF)

**RESULTS AND DISCUSSION**

Study of the factors affecting the results of the autoclave:

**Individual factors affecting the results of the autoclave test**

**CaO%:** CaO% selected to be as the independent variable, the final form of this model is as shown in Table 1. The relationship between the residuals and the estimated readings of the autoclave based on CaO and the relationship between the actual readings and the estimated readings of the autoclave based on CaO are presented in Fig. 1 and 2. The distribution of residuals is shown in Fig. 3.

**MgO%:** MgO% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 2. The relationship between the residuals and the estimated readings of the autoclave based on MgO and The relationship between the actual readings and the estimated readings of the autoclave based on MgO are presented in Fig. 4 and 5. The distribution of residuals is shown in Fig. 6.

**SiO<sub>2</sub>%:** SiO<sub>2</sub>% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 3. The relationship between the residuals and the estimated readings of the autoclave based on SiO<sub>2</sub> and the relationship between the actual readings and the estimated readings of the autoclave based on SiO<sub>2</sub> are presented in Fig. 7 and 8. The distribution of residuals is shown in Fig. 9.

**Al<sub>2</sub>O<sub>3</sub>%:** Al<sub>2</sub>O<sub>3</sub>% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 4. The relationship between the residuals and the estimated readings of the autoclave based on Al<sub>2</sub>O<sub>3</sub> and the relationship between the actual readings and the estimated readings of the autoclave based on Al<sub>2</sub>O<sub>3</sub> are presented in Fig. 10 and 11. The distribution of residuals is shown in Fig. 12.

**Fe<sub>2</sub>O<sub>3</sub>%:** Fe<sub>2</sub>O<sub>3</sub>% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 5. The relationship between the residuals and the estimated readings of the autoclave based on Fe<sub>2</sub>O<sub>3</sub> and the relationship between the actual readings and the estimated readings of the autoclave based on Fe<sub>2</sub>O<sub>3</sub> are presented in Fig. 13 and 14. The distribution of residuals is shown in Fig. 15.

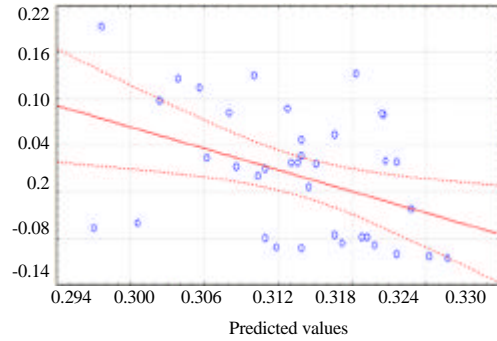


Fig. 1: The relationship between the residuals and the estimated readings of the autoclave based on CaO; Predicted vs. Residual scores dependent variables: AUTO\_EXP

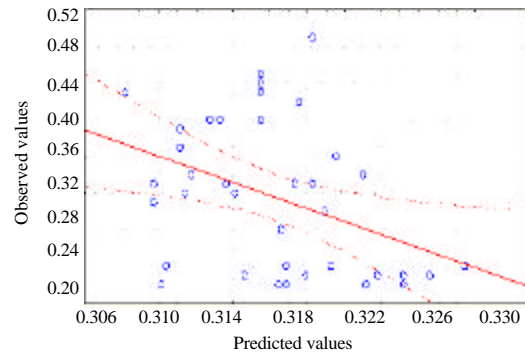


Fig. 2: The relationship between the actual readings and the estimated readings of the autoclave based on CaO; Predicted vs. observed values dependent variables: AUTO\_EXP

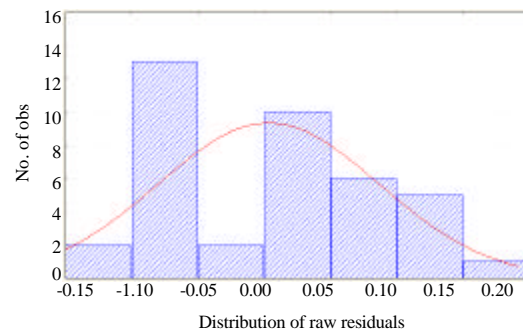


Fig. 3: Histogram and normal distribution of residual values depending on CaO

**SO<sub>3</sub>%:** SO<sub>3</sub>% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 6. The relationship between the residuals and the estimated readings of the autoclave based on SO<sub>3</sub> and the relationship between the actual readings and the estimated

Table 1: Linear regression results of the autoclave based on CaO%

Dependent variabkles	Independent var. (%)	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	CaO	0.96839035	0.93777987	572.7348	0.081910287	0.968

Table 2: Results of linear regression of the autoclave depending on MgO

Dependent variabkles	Independent variabkles	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	MgO	0.9644914	0.93983164	593.5612	0.080548430	0.969

Table 3: Results of the linear regression of the autoclave based on SiO<sub>2</sub>

Dependent variabkles	Independent	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	SiO <sub>2</sub>	0.96779167	0.93495284	561.565	0.082669752	0.96

Table 4: Results of linear regression of the autoclave depending on Al<sub>2</sub>O<sub>3</sub>

Dependent variabkles	Independent	Multiple R	R <sup>2</sup>	Adjusted	S	Beta
Auto exp.	Al <sub>2</sub> O <sub>3</sub>	0.9712094	0.94320569	631.6116	0.078226391	0.971

Table 5: Linear regression results of the autoclave based on Fe<sub>2</sub>O<sub>3</sub>

Dependent variabkles	Independet variabkles	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	Fe <sub>2</sub> O <sub>3</sub>	0.92007968	0.84654662	209.6322	0.128635609	0.92

Table 6: Results of linear regression of the scale based on SO<sub>3</sub>

Dependent variabkles	Independent var.	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	SO <sub>3</sub>	0.97630404	0.95316957	773.4382	0.071061937	0.976

Table 7: Results of linear regression of the autoclave based on free lime

Dependent variabkles	Independent variabkles	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	Free lime	0.96485076	0.93093707	512.2222	0.086297003	0.965

Table 8: Results of linear regression of the autoclave depending on LOI

Dependent variabkles	Independent variabkles	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	L-O-I	0.91665561	0.84025751	199.8229	0.13245134	0.917

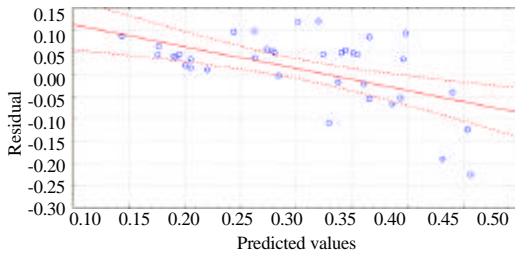


Fig. 4: The relationship between the residual and the estimated readings of the autoclave based on MgO; Predicted vs. residual scores dependent variables: AUTO\_EXP

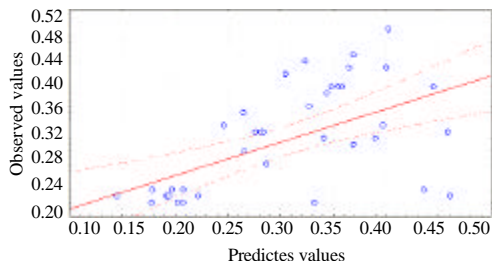


Fig. 5: The relationship between the actual readings and the estimated readings of the autoclave based on MgO; Predicted vs. observed values dependent variables: AUTO\_EXP

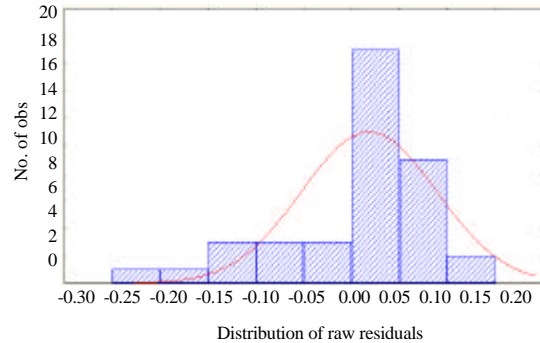


Fig. 6: Histogram and normal distribution of residual values depending on MgO

readings of the autoclave based on SO<sub>3</sub> are presented in Fig. 16 and 17. The distribution of residuals is shown in Fig. 18.

**Free lime%:** Free lime% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 7. The relationship between the residuals and the estimated readings of the autoclave based on Free Lime and the relationship

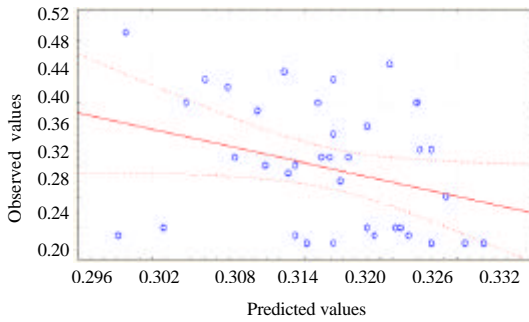


Fig. 7: The relationship between the residual and the estimated readings of the autoclave based on  $\text{SiO}_2$ ; Predicted vs. observed values dependent variables: AUTO\_EXP

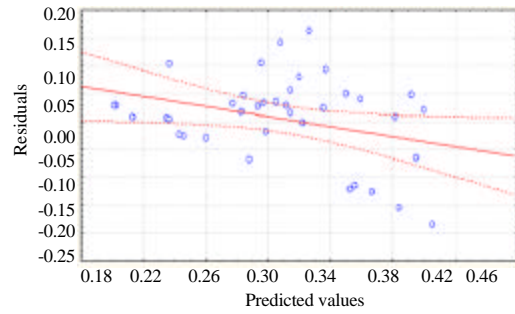


Fig. 10: The relationship between the residual and the estimated readings of the autoclave based on  $\text{Al}_2\text{O}_3$ ; Predicted vs. observed values dependent variables: AUTO\_EXP

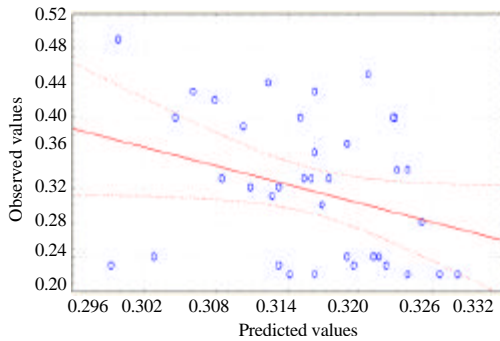


Fig. 8: The relationship between the actual readings and the estimated readings of the autoclave based on  $\text{SiO}_2$ ; Predicted vs. observed values dependent variables: AUTO\_EXP

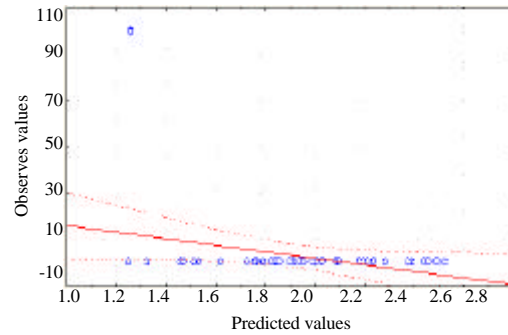


Fig. 11: The relationship between the residual and the estimated readings of the autoclave based on  $\text{Al}_2\text{O}_3$ ; Predicted vs. observed values dependent variables: AUTO\_EXP

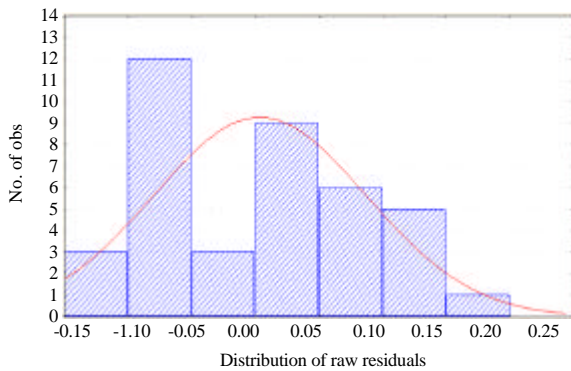


Fig. 9: Histogram and normal distribution of residual values based on  $\text{SiO}_2$

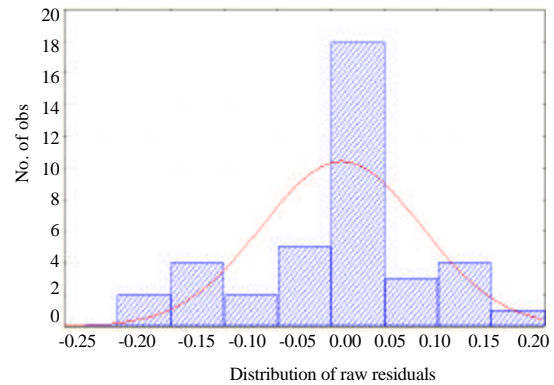


Fig. 12: Histogram and normal distribution of residual values depending on  $\text{Al}_2\text{O}_3$

between the actual readings and the estimated readings of the autoclave based on free lime are presented in Fig. 19 and 20. The distribution of residuals is shown in Fig. 21.

**LOI%:** L.O.I% was used as the independent variable in developing this model. The final form of this model

is as illustrated in Table 8. The relationship between the residuals and the estimated readings of the autoclave based on LOI and the relationship between the actual readings and the estimated readings of the autoclave based on LOI are presented in Fig. 22 and 23. The distribution of residuals is shown in Fig. 24.

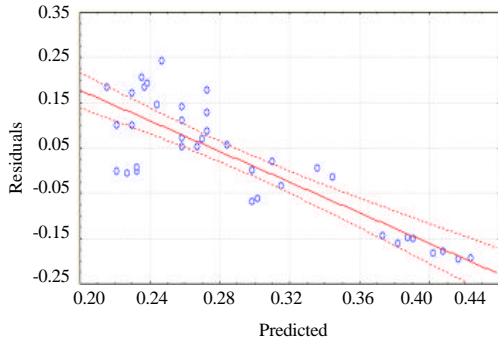


Fig. 13: The relationship between the residual and the estimated readings of the autoclave based on  $\text{Fe}_2\text{O}_3$ ; Predicted vs. residual scores dependent variables: AUTO\_EXP

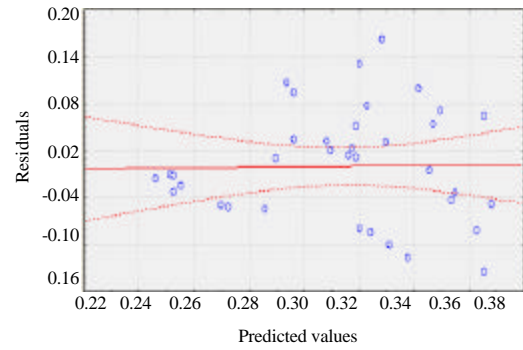


Fig. 16: The relationship between the residual and the estimator's estimated readings of the autoclave based on  $\text{SO}_3$ ; Predicted vs. residual scores dependent variables: AUTO\_EXP

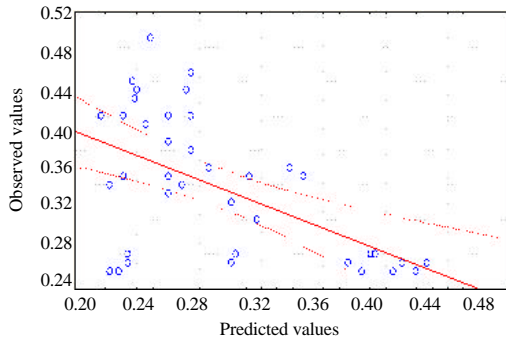


Fig. 14: The relationship between the actual readings and the estimated readings of the autoclave based on  $\text{Fe}_2\text{O}_3$ ; Predicted vs. observed values dependent variables: AUTO\_EXP

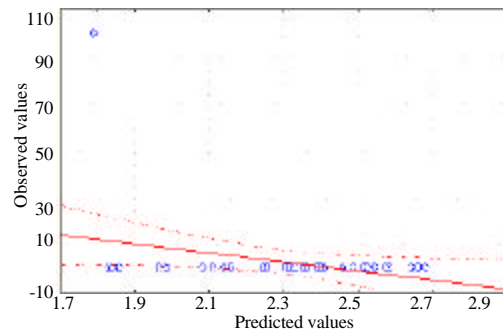


Fig. 17: The relationship between the actual and the estimator's estimated readings of the autoclave based on  $\text{SO}_3$ ; Predicted vs. observed values dependent variables: AUTO\_EXP

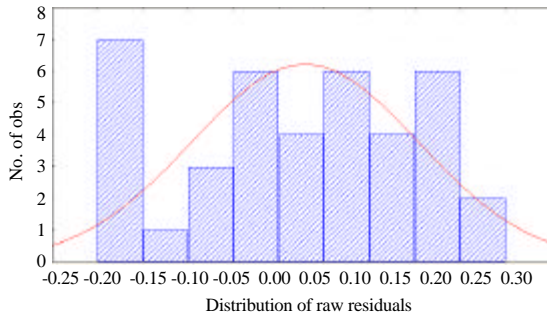


Fig. 15: Histogram and normal distribution of residual values depending on  $\text{Fe}_2\text{O}_3$

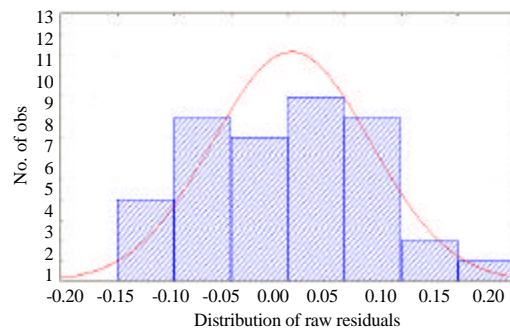


Fig. 18: Histogram and normal distribution of residual values depending on  $\text{SO}_3$

**IR%:** IR% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 9. The relationship between the residuals and the estimated readings of the autoclave based on IR and the relationship between the actual readings and the estimated readings of the autoclave based on IR are presented in Fig. 25 and 26. The distribution of residuals is shown in Fig. 27.

**LSF%:** LSF% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 10. The relationship between the residuals and the estimated readings of the autoclave based on LSF and the relationship between the actual readings and the estimated readings of the autoclave

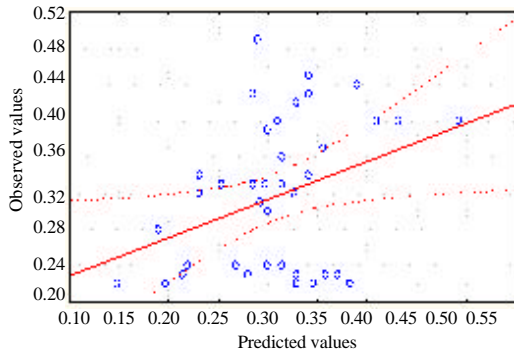


Fig. 19: The relationship between the residual and the estimated readings of the autoclave based on free lime; Predicted vs. observed values dependent variables: AUTO\_EXP

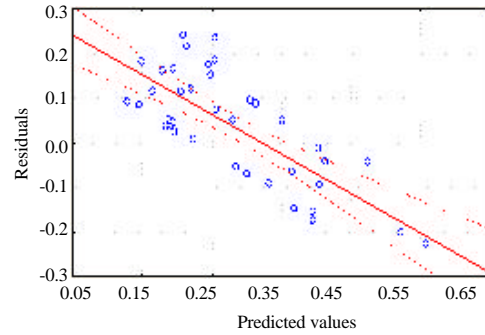


Fig. 22: The relationship between the residual and the estimated readings of the autoclave based on LOI; Predicted vs. residual scores dependent variables: AUTO\_EXP

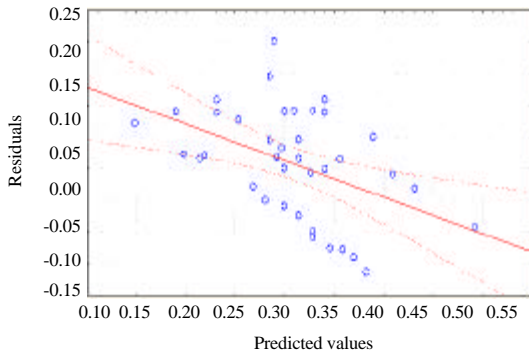


Fig. 20: The relationship between the actual readings and the estimated readings of the autoclave based on free lime; Predicted vs. observed values dependent variables: AUTO\_EXP

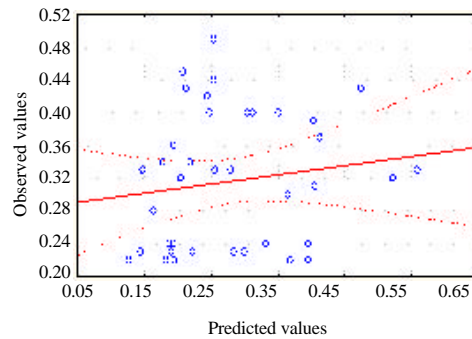


Fig. 23: The relationship between the actual and the estimated readings of the autoclave based on LOI; Predicted vs. observed values dependent variables: AUTO\_EXP

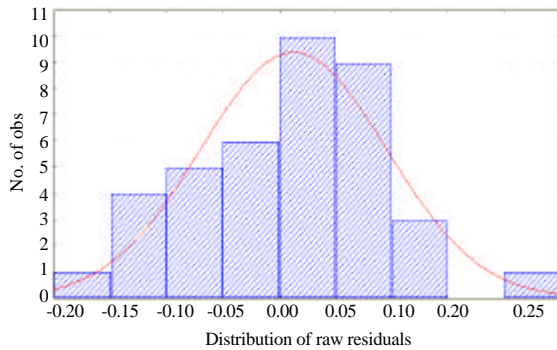


Fig. 21: Histogram and normal distribution of residual values based on free lime

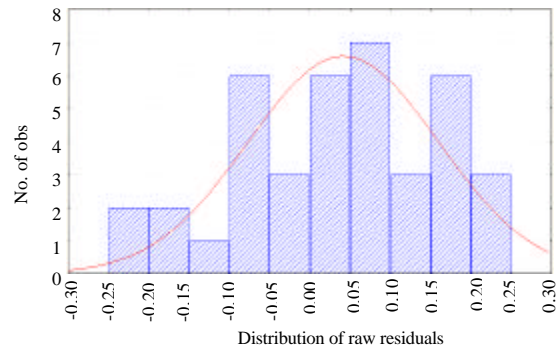


Fig. 24: The histogram and the natural distribution of residual values based on LOI

based on L.S.F are presented in Fig. 28 and 29. The distribution of residuals is shown in Fig. 30: Table 9 and 10.

**IST-MIN%:** IST-MIN % was used as the independent variable in developing this model. The final form of this

model is as illustrated in Table 11. The relationship between the residuals and the estimated readings of the autoclave based on IST-MIN and the relationship between the actual readings and the estimated readings of the autoclave based on IST-MIN are presented in Fig. 31 and 32. The distribution of residuals is shown in Fig. 33.

Table 9: Results of the linear regression of the autoclave depending on the IR

Dependent variables	Independent variables	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	IR	0.93354730	0.87151055	257.7441	0.117708199	0.934

Table 10: Results of the linear regression of the autoclave based on LSF

Dependent var.	Independent var.	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	L-S-F	0.96857396	0.93813551	576.3458	0.081675855	0.969

Table 11: Results of linear regression of the autoclave based on IST-MIN

Dependent variables	Independent variables	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	IST-MIN	0.95545881	0.91290154	398.2878	0.096912150	0.955

Table 12: Results of the linear regression of the autoclave based on FST-MIN

Dependent variables	Independent variables	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	FST-MIN	0.96219655	0.92582220	374.2827	0.08943550	0.962

Table 13: Results of linear regression of the autoclave based on Blaine

Dependent variables	Independent variables	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta
Auto exp.	Blaine	0.97406992	0.94881220	704.3644	0.07424421	0.974

Table 14: Results of linear regression of the autoclave depending on MgO.CaO

Dependent variables	Independent var.	Multiple R	R <sup>2</sup>	Adjusted F	SE	Beta CaO	Beta
Auto exp.	MgO+CaO%	0.785141	0.957899	416.6913	0.069191	0.468	0.52

Table 15: Results of the linear regression of the autoclave based on MgO, CaO, Blaine

Dependent variables	Independent var.	Multiple R	R <sup>2</sup>	Error	Adjusted F	SE	Beta.CaO	Beta
Auto exp.	MgOCaO.Blaine	0.97911	0.95866	278.2	0.06917	0.158	0.453	0.3

Table 16: Results of linear regression of the autoclave depending on MgO.CaO.SO<sub>3</sub>

DeP var.	Indep.	Mul.R	R <sup>2</sup>	Adj. F	Error	Beta.MgO	Beta.CaO	Beta.SO <sub>3</sub>
Auto exp.	Mgo.Cao.SO <sub>3</sub>	0.97967	0.959	286.5	0.0682	0.386	0.087	0.514

Table 17: Results of the linear regression of the autoclave depending on MgO.CaO.SO<sub>3</sub>.Blaine

Dep var.	Indep.	R	R <sup>2</sup>	Adj. F	Error	Beta.	Beta.Ca	Beta.SO	Blaine
Auto exp.	MgO.CaO.SO <sub>3</sub> .Blaine	0.98	0.9604	212.4	0.068	0.35	0.1	0.45	0.28

**FST-MIN%:** FST-MIN% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 12. The relationship between the residuals and the estimated readings of the autoclave based on FST-MIN and The relationship between the actual readings and the estimated readings of the autoclave based on FST-MIN are presented in Fig. 34 and 35.

**Blaine%:** Blaine% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 13. The relationship between the residuals and the estimated readings of the autoclave based on Blaine and the relationship between the actual readings and the estimated readings of the autoclave based on Blaine are presented in Fig. 37 and 38. The distribution of residuals is shown in Fig. 39.

**Study of the factors affecting the results of the autoclave in groups**

**MgO, CaO:** MgO, CaO% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 14-17. The relationship

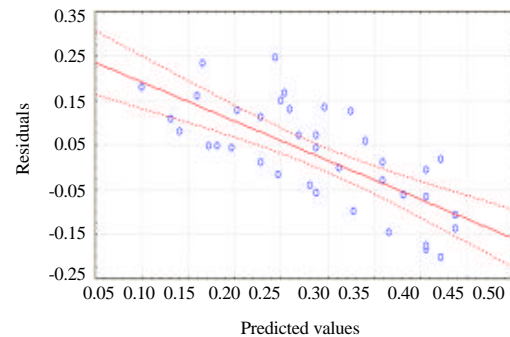


Fig. 25: The relationship between the residual and the estimated readings of the autoclave based on IR; Predicted vs. residual scores dependent variables: AUTO\_EXP

between the residuals and the estimated readings of the autoclave based on MgO, CaO and the relationship between the actual readings and the estimated readings of the autoclave based on MgO, CaO are presented in Fig. 40 and 41. The distribution of residuals is shown in Fig. 42. it is obvious that the residuals are almost normally distributed and the residuals gathered after zero.



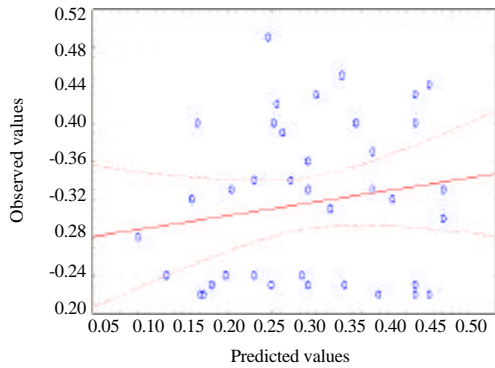


Fig. 26: The relationship between the actual readings and the estimated readings of the autoclave based on the IR; Predicted vs. observed values dependent variables: AUTO\_EXP

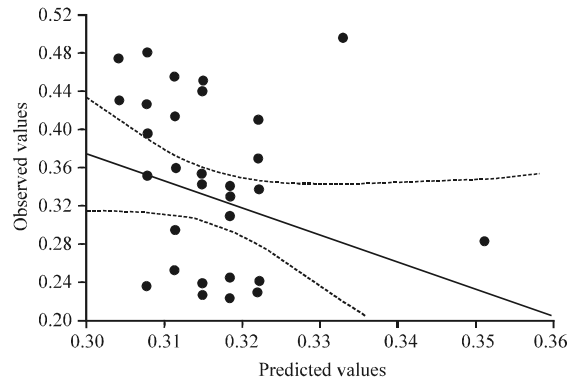


Fig. 29: The relationship between the actual readings and the estimated readings of the autoclave based on LSF; Predicted vs. observed values dependent variables: AUTO\_EXP

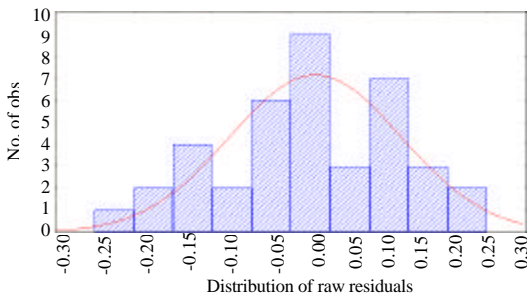


Fig. 27: Histogram and normal distribution of residual values depending on the IR

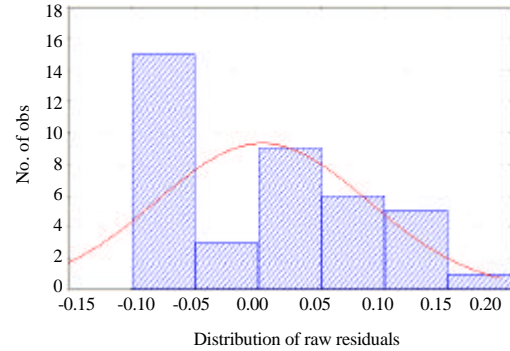


Fig. 30: The histogram and the natural distribution of the remaining values based on LSF

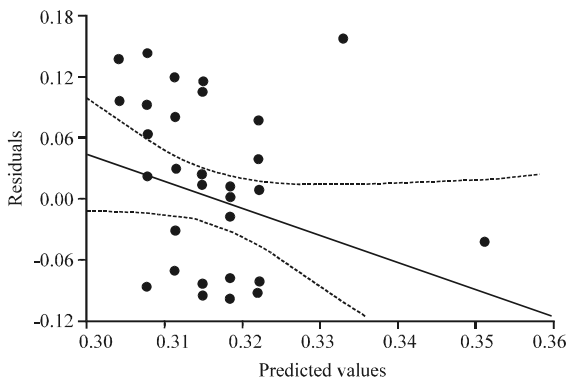


Fig. 28: The relationship between the residual and the estimated readings of the autoclave based on LSF; Predicted vs. residual scores dependent variables: AUTO\_EXP

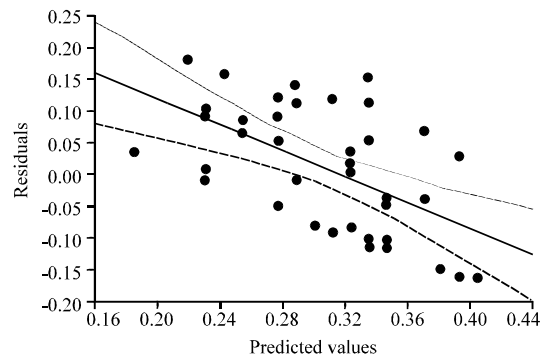


Fig. 31: The relationship between the residual and the estimated readings of the autoclave based on IST-MIN; Predicted vs. residual scores dependent variables: AUTO\_EXP

MgO, CaO, Blane: MgO, CaO, Blane% was used as the independent variable in developing this model. The final form of this model is as illustrated in Table 15. The relationship between the residuals and the estimated

readings of the autoclave based on MgO, CaO, Blane and the relationship between the actual readings and the estimated readings of the autoclave based on

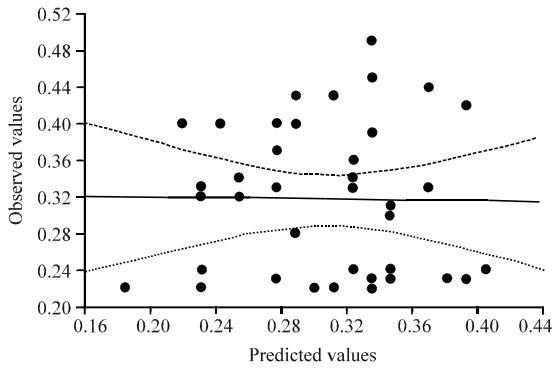


Fig. 32: The relationship between the actual readings and the estimated readings of the autoclave based on the IST-MIN; Predicted vs. observed values dependent variables: AUTO\_EXP

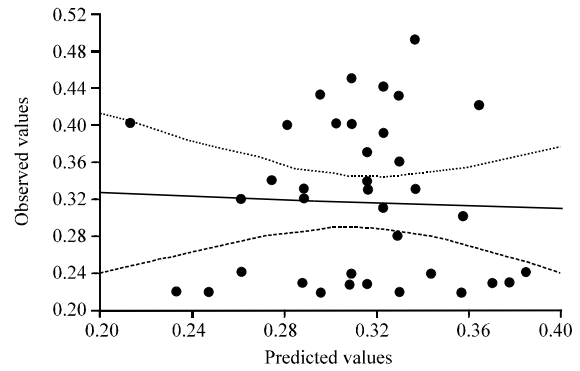


Fig. 35: The relationship between the actual readings and the estimated readings of the autoclave based on FST-MIN; Predicted vs. observed values dependent variables: AUTO\_EXP

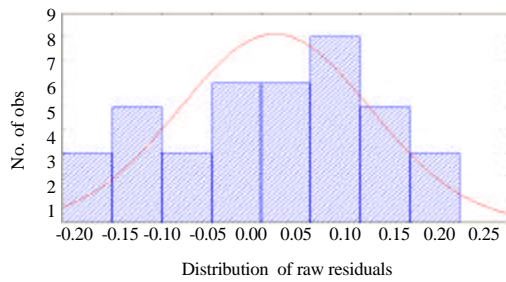


Fig. 33: Histogram and normal distribution of residual values based on SIT-MIN

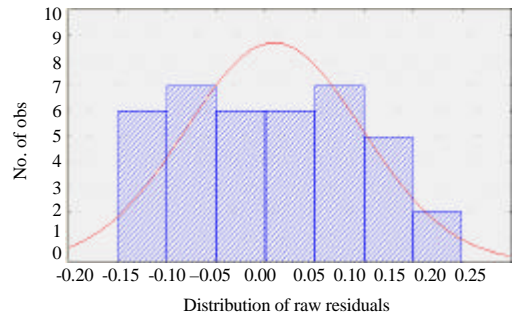


Fig. 36: The histogram and the natural distribution of the residual values of the autoclave based on FST-MIN

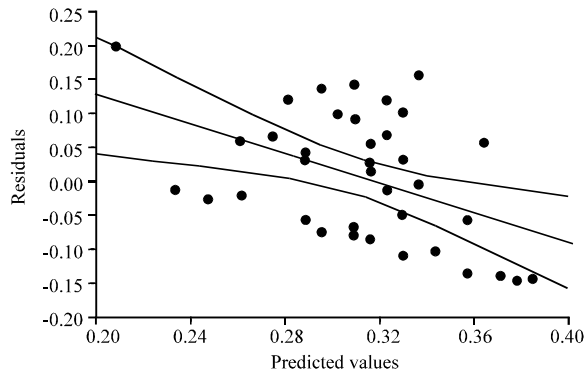


Fig. 34: The relationship between the residual and the estimated readings of the autoclave based on FST-MIN; Predicted vs. observed values dependent variables: AUTO\_EXP

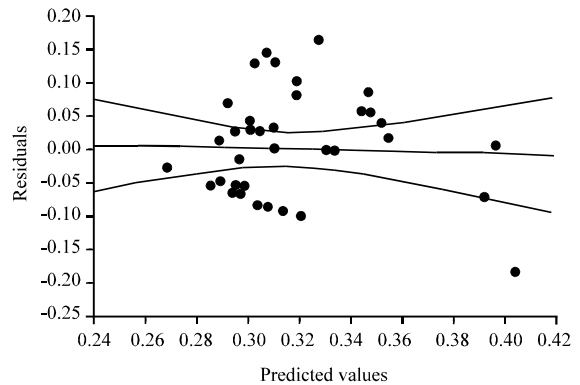


Fig. 37: Relationship between the residual and the estimated readings of the autoclave based on BLINE; Predicted vs. residual scores dependent variables: AUTO\_EXP

MgO, CaO, Blane are presented in Fig. 43 and 44. The distribution of residuals is shown in Fig. 45.

**MgO, CaO, SO<sub>3</sub>:** MgO, CaO, SO<sub>3</sub>% was used as the independent variable in developing this model. The final

form of this model is as illustrated in Table 16. The relationship between the residuals and the estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub> and

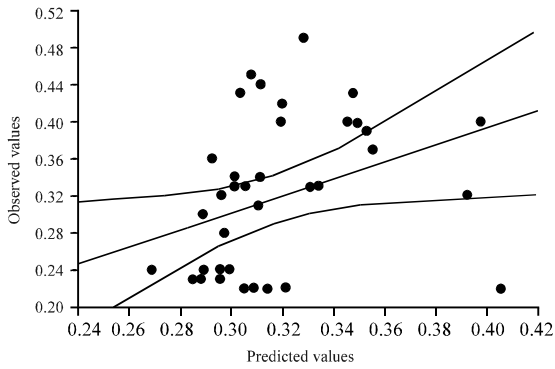


Fig. 38: The relationship between the actual values and the estimated values of the autoclave based on Blaine predicted vs. Predicted vs. observed values dependent variables: AUTO\_EXP

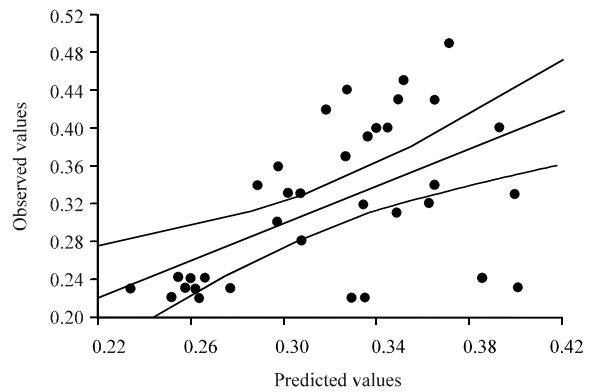


Fig. 41: The relationship between the actual readings and the estimated readings of the autoclave based on MgO, CaO; Predicted vs. observed values dependent variables: AUTO\_EXP

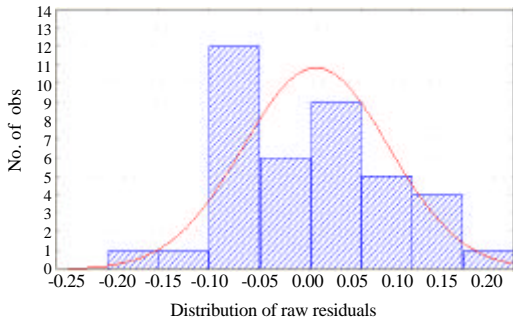


Fig. 39: Histogram and normal distribution of residual values based on Blaine

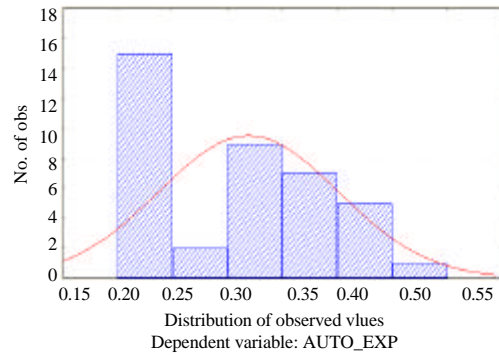


Fig. 42: The histogram and the natural distribution of the residual values of the autoclave based on MgO, CaO

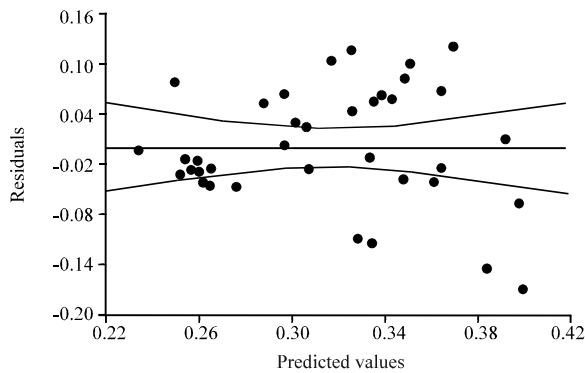


Fig. 40: The relationship between the residual and the estimated readings of the autoclave based on MgO, CaO; Predicted vs. residual scores dependent variables: AUTO\_EXP

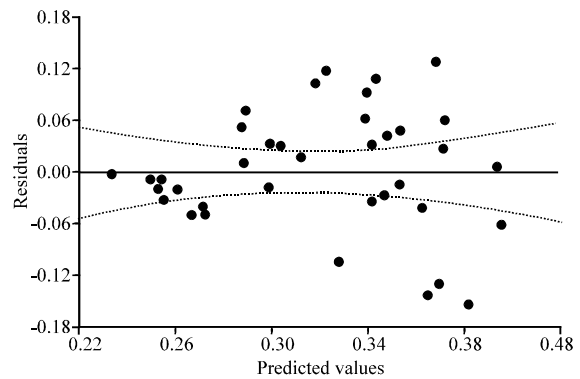


Fig. 43: Relationship between the residual and the estimated readings of the autoclave based on MgO, CaO, Blaine; Predicted vs. residual scores dependent variables: AUTO\_EXP

the relationship between the actual readings and the estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub> are presented in Fig. 46 and 47. The distribution of residuals is shown in Fig. 48.

MgO, CaO, SO<sub>3</sub>, Blaine: MgO, CaO, SO<sub>3</sub>, Blaine was used as the independent variable in developing this

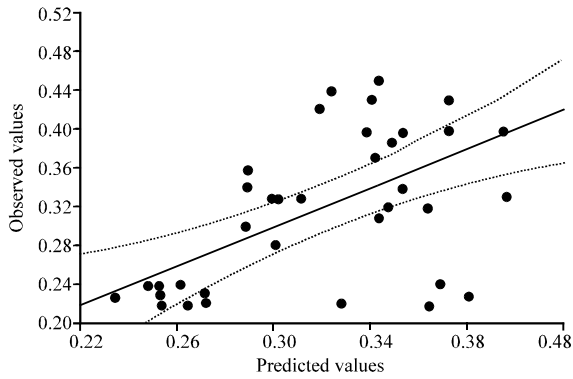


Fig. 44: The relationship between the actual readings and the estimated readings of the autoclave based on MgO, CaO, Blane; Predicted vs. observed values dependent variables: AUTO\_EXP

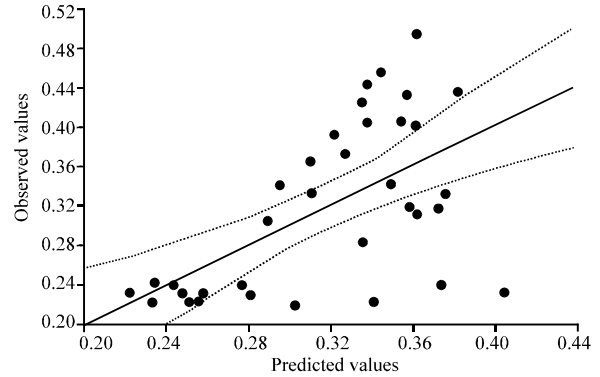


Fig. 47: The relationship between the actual readings and the estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub>; Predicted vs. observed values dependent variables: AUTO\_EXP

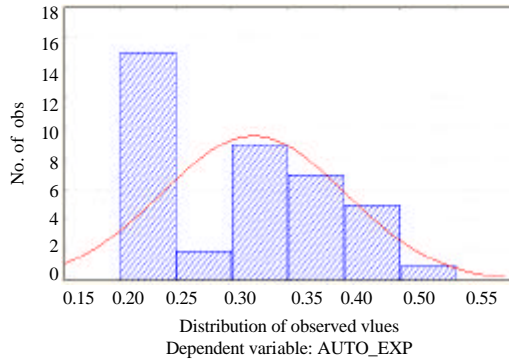


Fig. 45: Histogram and normal distribution of the remaining values of the autoclave based on MgO, CaO, Blane

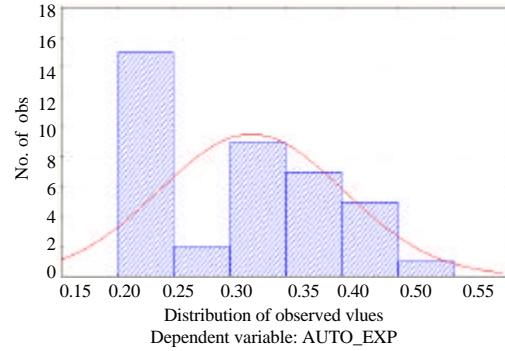


Fig. 48: The histogram and the natural distribution of the remaining values of the autoclave based on MgO, CaO, SO<sub>3</sub>

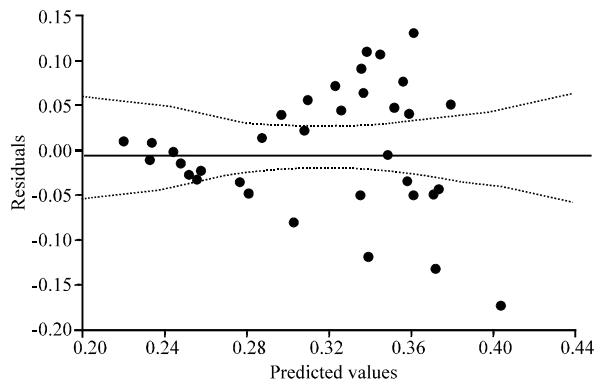


Fig. 46: Relationship between the residual and the estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub>; Predicted vs. residual scores dependent variables: AUTO\_EXP

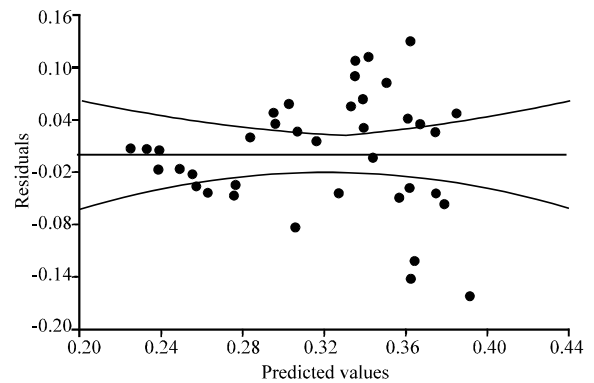


Fig. 49: The relationship between the residual and the estimated readings of the autoclave based on MgO, SO<sub>3</sub>, CaO, Blane; Predicted vs. residual scores dependent variables: AUTO\_EXP

model. The final form of this model is as illustrated in Table 17. The relationship between the residuals and the

estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub>, Blane and the relationship between the actual

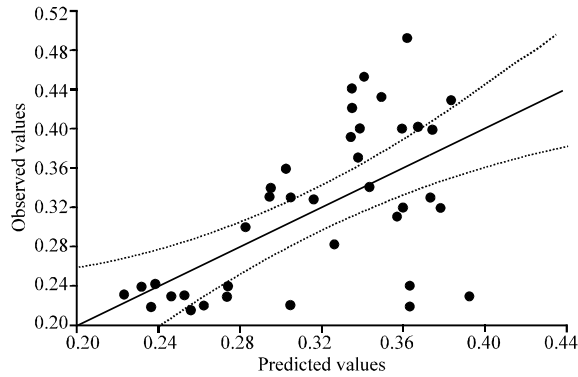


Fig. 50: Relationship between the actual readings and the estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub>, Blane; Predicted vs. observed values dependent variables: AUTO\_EXP

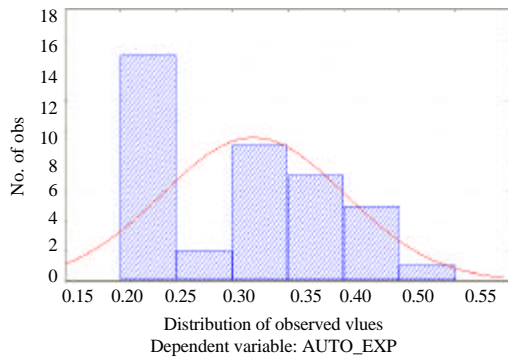


Fig. 51: The histogram and the natural distribution of the remaining values of the autoclave based on MgO, CaO, SO<sub>3</sub>, Blanel

readings and the estimated readings of the autoclave based on MgO, CaO, SO<sub>3</sub>, Blane are presented in Fig. 49 and 50. The distribution of residuals is shown in Fig. 51.

The results of the correlation coefficient (R) and (R<sup>2</sup>) for individual factors are very close and it was ranged between (0.916-0.976) and (0.84-0.953) for (R) and (R<sup>2</sup>), respectively, the results of the correlation coefficient (R) for (free lime, L.S.F, SiO<sub>2</sub>, CaO, MgO) compounds was about (0.967). The results of both the IR, L.o.1 and Fe<sub>2</sub>O<sub>3</sub> were close with the value of correlation coefficient (R) with about (0.916). The results of F-values (F) for individual factors are came in varying values in range of (199-773), te results of both the IR, LO1 and Fe<sub>2</sub>O<sub>3</sub> were close with the F-values (F) and the Standard Error (SE) with about (199) and (0.117), respectively. The results of (Blane) and aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) and sulfur compounds (SO<sub>3</sub>) were convergent in the correlation coefficient (R) of these compounds (0.971).

When studied the affecting factors on the results of the autoclave in groups, the correlation coefficient of (MgO, CaO) group was 0.785 and (MgO, CaO and Blane) group was 0.979 (MgO, CaO, SO<sub>3</sub>) was 0.979 and (MgO, CaO, SO<sub>3</sub> and Blane) was 0.98. It is clear that the fineness of cement is the one of most interesting feature influencing the soundness of cement and the value of the correlation coefficient (R) was improved when the fineness appear in models.

Fineness of cement is the most interesting factor affecting the soundness of cement. From this model it is clear that the autoclave expansion decreases with the increase in cement fineness. For the results of the individual factors the distribution of residuals are distributed normally and the residuals concentrated around the center (zero). This gives an indication that the models are adequate and no error in analysis and this the more suitable and recommended while the factors in groups shows a clear intercept to the side.

## CONCLUSION

According to the results obtained in this study from the autoclave test, the following can be concluded: the multiple linear regression was found to be very suitable for predicting the autoclave expansion of Portland cement. Noted that, there is no significant difference in the value of correlation coefficient when studying the factors individually or in the form of groups, so, it is preferable to use equations with individual factors for ease of research.

## ACKNOWLEDGMENTS

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