Formulation of optimization model of raw material composition to achieve clinker quality standards (Case study PT Semen Padang Plant IV)

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Abstract. Cement making process required four main raw materials, Lime Stone as a source of CaCO₃, Silica Stone as a source of SiO₂, Clay as a source of Al₂O₃ and Iron Sand as a source of Fe₂O₃. Proportion of raw materials approximately 80% CaCO₃, 15% SiO₂, 3% Al₂O₃ and the remaining 2% for Fe₂O₃. Due to operational constraints in the mine area, Indarung IV plant is experiencing a shortage of SiO₂ source material that is Silica Stone, to anticipate this condition selected Pozzolan as alternative raw material because the SiO₂ content in Pozzolan is above 60%. This research uses Linear Programming to get formulation model of optimization of raw material composition with Pozzolan as a substitute of Silica stone by minimizing cost. Ash composition factors and calories of fuel are not made into consideration. The results of this study obtained the most optimal raw material composition with minimal cost and meet the standard strength three days clinker min. 200 kg/cm², by inputting the oxide composition of each raw material and the minimum and maximum constraint into the model formulation. The use of Pozzolan as a substitute raw material for Silica increases raw material costs 265.74 rp/ton.

1. Introduction
PT Semen Padang is the oldest cement plant in Indonesia established by the Dutch government on March 18, 1910, under the name NV Nederlandsch Indische Portland Cement Maatschappij (NV NIPCM). At that time, Semen Padang was not only the first cement plant in Indonesia but also the first in Southeast Asia. The raw materials used in the cement making process are Limestone (limestone) as the main ingredients ±80%, Silica ±9%, Clay ±9%, and Iron sand ±1%, while other additional materials are added in finish mills such as Pozzolan, Gypsum, and Fly ash. With certain compositions, Limestone, Silica, Clay and Iron Sand raw materials are milled in the raw mill to produce a raw mix which is then homogenized in Silo. Raw mix is feed into the kiln system for calcination, sintering, clinkerization at ±1.450 °C, and quenching in Cooler to ±100 °C temperature. Clinker is formed, then milled in cement mill with other additive materials (gypsum, limestone, and pozzolan) to produce cement.

As a result of the limited new mining permit in Bukit Ngalau, in 2014 silica mining was moved to the Karang Putih area. There is a difference of material composition of silica content mined in Karang
Putih with mined in Bukit Ngalau area. The composition of Standard Silica Stone SiO₂ content Minimum 65% and Al₂O₃ below 10% while Silica material from white hill reef containing Al₂O₃ above 10% (High Content Alumina) and SiO₂ content below 65%, this impact on increasing Silica consumption at the plant. Selection of Pozzolan as an alternative material of Silica substitute due to SiO₂ content in Pozzolan above 65% as a minimum requirement of a SiO₂ source of raw mixed raw material, as in the table 1 below:

| Characteristics | Silica stone % | Pozzolan %  |
|-----------------|---------------|-------------|
| SiO₂            | 68-70         | 65-70       |
| Al₂O₃           | 10 <          | 15-18       |

The use of pozzolan as a substitute for the Silica source requires the right composition to get the quality of clinker by the standard. This standard is the basis of the researcher to examine the formulation of the optimization model of the composition of raw materials to obtain a standard clinker compressive strength (min 200 kg/cm²). Changes in the composition of raw materials in the process of making clinker have an impact on the change of raw mix design, it is needed formulation model to formulate the change of Raw Mix to achieve the quality of clinker. The purpose of this research is to determine the Formulation of Optimization Model of Raw Material Composition to obtain Klinker quality standard in Indarung IV plant.

Limitations of this research problem are as follows:
1. The research was conducted at Indarung IV plant of PT Semen Padang in the period from October 2017 to January 2018.
2. The study was conducted without taking into account the composition of Ash and calories of fuel (raw coal).
3. Feeding Kiln average 310 tons/hour.
4. Strong clinker target minimum 200 kg/cm².
5. Raw material data in June 2018 is used as a comparison of raw material cost between Pozzolan usages compared to Silica.
6. Material composition using Dry Basis.

2. Literature review

2.1. Linear programming

A linear program with a linear optimization technique is an attempt to solve a problem, in which all the mathematical functions used in a linear program are linear functions.

According to Mokhtar S. Bazaraa, et al. in Haryati (2011) research stated that linear program is an optimization problem that aims to maximize or minimize a linear function that satisfies constraints in the form of equations or linear inequalities. Meanwhile, according to Johannes Supranto (2009) linear program is one of the techniques in operation research to solve the problem of optimization by using equations and linear inequalities to find the optimum solution by considering the existing restrictions.

According to Mulyono (2004), Linear Programming (Linear Programming abbreviated LP) is one of the most widely used and widely known Operating Research technique. The Linear program is a mathematical method of allocating scarce resources to achieve goals. The Linear Program (Linear Programming) is a mathematical technique designed to help operations managers plan and make decisions necessary to allocate resources based on Heizer and Render (2006).
2.2. Linear regression
Regression analysis is one of the data analysis techniques in statistics that often used to examine the relationship between several variables and predict variables (Kutner, Nachtsheim and Neter, 2004). The term "regression" was first put forward by Sir Francis Galton (1822-1911), the famous anthropologist and meteorologist from England. In his paper entitled "Regression towards mediocrity in hereditary stature," Which is loaded in Journal of the Anthropological Institute, volume 15, p. 246-263, in 1885. Galton explains that seed descendants do not tend to resemble their parent beans regarding magnitude, but are more mediocre (closer to the average) smaller than the parent if the parent is large and larger than its mother if its mother is very small (Draper and Smith, 1992). The study included the study of theory and its application on case studies accompanied by analysis techniques and data processing with help SPSS software.

3. Research methodology
3.1. Data collection
Indarung IV plant started using Pozzolan as a source of SiO₂, at the beginning of October 2017. So to know the effect of Silica turnover with pozzolan to use the raw materials used, then the data is taken for 5 months, that is June 2018 (pure Silica usage), October 2017 (pozzolan usage), November 2017 (pozzolan usage), December 2017 (pozzolan usage), and January 2018 (use of pozzolan).

3.2. Data standardization
This stage includes the processing of data that has been obtained from the data collection to obtain the purpose of this study. Processed data is data that yields compressive strength >200 kg/cm², using regression analysis to find the relationship:
1. Clinker characteristic relationship with compressive strength.
2. The characteristic relationship of the kiln feed with clinker characteristics.

3.3. Raw material requirement formulation
The usual method often used for production planning is linear programming. Linear programming can be used as a raw material planning tool. This model generally covers the problem of fluctuation of an oxide of each raw material Raw Mix, Limestone, Pozzolan, Silica, Iron Sand and Clay to get the best combination of raw materials (optimal) in quality and cost.

3.4. Model verification and validation
Verification model aims to check whether the logic model used has been by the data used and know the truth of the model created. The model verification process consists of verification of the model components and the model dimension test. The validation model aims to determine whether the model has represented the real system and solve problems in the company. Model validation is done by using face validity and comparing the output of each component model with a target to be achieved.

3.5. Implementation and analysis model
Implementation of the model is done to determine the combination of Raw Mix raw material output planning. The data required in the implementation of this model consists of:
1. Data of raw material oxide composition.
2. Raw material price per ton.

3.6. Conclusions and recommendations
This part contains conclusions from the results of research conducted and suggestions for further research.
4. Model development

Below was a characteristic system of raw materials, with Oxides contained in each raw material:

![Image](characteristic_system.png)

**Figure 1.** Characteristic system

4.1. Notation, Symbol, and Units

The notation used in making the model of raw material composition in Clinker making process was raw material type \((i)\). The form of notation, symbols, and units of the model can be seen in Table 2.

| Notation | Symbol | Units |
|----------|--------|-------|
| The number of raw materials \(i\) used | \(X_i\) | Ton |
| The cost of purchasing raw materials \(i\) per Ton | \(C_i\) | Rp./ton |
| The target value of SiO\(_2\) | \(T\) | % |
| SiO\(_2\) content per raw material type \(i\) | \(S_i\) | % |
| Target value Al\(_2\)O\(_3\) | \(U\) | % |
| Al\(_2\)O\(_3\) content per raw material type \(i\) | \(A_i\) | % |
| The target value of Fe\(_2\)O\(_3\) | \(V\) | % |
| Fe\(_2\)O\(_3\) content per raw material type \(i\) | \(F_i\) | % |
| The target value of CaO | \(W\) | % |
| CaO content per raw material type \(i\) | \(C_i\) | % |
| The target value of MgO | \(Y\) | % |
| MgO content per raw material type \(i\) | \(M_i\) | % |

4.2. Identification of Data Requirement and Data Standardization

The data required in the composition of raw material composition, which consists of the data content of SiO\(_2\), Al\(_2\)O\(_3\), Fe\(_2\)O\(_3\), CaO, and MgO on each raw material, and data content in SiO\(_2\), Al\(_2\)O\(_3\), Fe\(_2\)O\(_3\), CaO, and MgO Clinker and Kiln Feed.

4.2.1. Raw material content data

The raw material content data can be seen in Table 3.

| Raw material content data | SiO\(_2\) | Al\(_2\)O\(_3\) | Fe\(_2\)O\(_3\) | CaO | MgO |
|--------------------------|---------|----------------|----------------|-----|-----|
| Limestone                | 0.1014  | 0.0166         | 0.0107         | 0.4697 | 0.0048 |
| Pozzolan                 | 0.7440  | 0.1552         | 0.0140         | 0.0102 | 0.0063 |
| Iron sand                | 0.2587  | 0.0722         | 0.4878         | 0.0331 | 0.0082 |
| Clay                     | 0.4202  | 0.2940         | 0.1168         | 0.0093 | 0.0033 |
| Composition required (%) | Minimum | 11.03          | 2.89           | 1.98 | 40.90 | 0.23 |
|                         | Maximum | 17.24          | 4.25           | 2.62 | 45.66 | 0.84 |
4.2.2. Characteristics data kiln feeds, clinker, and strength

Table 4. Kiln feeds, clinker, and strength 3D

| Date     | Z SiO$_2$ | Z Al$_2$O$_3$ | Z Fe$_2$O$_3$ | Z CaO | Z MgO | Z Strength 3D |
|----------|-----------|---------------|---------------|-------|-------|---------------|
| 10/8/17  | -0.18     | 0.04          | -1.03         | 1.71  | -2.92 | -0.29         |
| 10/15/17 | -2.01     | 1.28          | -0.76         | 1.39  | -0.26 | 0.09          |
| 10/22/17 | 0.09      | 0.39          | -1.27         | 0.72  | -0.92 | -0.99         |
| 10/29/17 | 0.69      | 1.42          | -0.88         | 0.69  | 0.66  | -0.23         |
| 11/5/17  | -2.06     | 0.85          | -1.04         | 1.55  | 1.04  | -0.55         |
| 11/12/17 | -0.67     | 0.22          | 0.09          | 0.13  | 1.14  | 0.72          |
| 11/19/17 | 0.17      | 1.22          | 1.41          | -2.04 | 1.10  | -0.17         |
| 11/26/17 | -0.75     | -0.33         | 0.97          | -0.09 | -0.06 | 1.49          |
| 12/3/17  | 0.64      | -1.01         | 0.45          | -0.28 | -0.25 | -0.99         |
| 12/10/17 | 0.22      | 0.92          | -0.75         | -0.69 | -0.93 | 0.66          |
| 12/31/17 | -0.58     | -0.18         | -0.71         | -0.67 | 0.16  | 0.53          |
| 1/7/18   | 0.64      | -0.19         | 0.99          | -0.28 | -0.47 | -1.31         |
| 1/14/18  | 0.81      | -1.04         | 0.86          | -0.52 | 0.42  | 2.57          |
| 1/21/18  | 0.26      | -1.02         | 1.88          | 0.41  | 0.01  | 0.72          |
| 1/28/18  | 1.71      | -0.84         | 0.75          | 0.22  | 0.77  | 0.34          |

Table 5. Raw material use data in kiln feeds and clinker

| Kiln Feed | Klinker |
|-----------|---------|
| SiO$_2$   | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO |
| 0.942     | 0.934 | 0.447      | -0.377 | 2.994 | 0.13 | 0.156 | -0.427 | 0.694 | -2.546 |
| 1.141     | 1.059 | 0.346 | -0.788 | 2.994 | -0.483 | -0.323 | -1.104 | 0.510 | -2.403 |
| 0.997     | 1.121 | 0.346 | -0.706 | 2.800 | 0.071 | -0.536 | -1.288 | 0.896 | -2.118 |
| 0.237     | 0.186 | -0.159 | 0.389 | 2.897 | -0.084 | -0.483 | -1.042 | 0.602 | -1.975 |
| 1.612     | 0.934 | 0.447 | -1.554 | 2.702 | -0.075 | 0.582 | 0.249 | 0.565 | -2.546 |
| 0.291     | 0.436 | 0.058 | 0.197 | 2.800 | -0.045 | -0.483 | -0.796 | 0.841 | -2.403 |
| -0.106    | 1.121 | -0.058 | 0.525 | 2.800 | -0.396 | -0.483 | -0.735 | 0.804 | -2.403 |
| 1.196     | 0.685 | 0.547 | -0.651 | 2.897 | -0.192 | -0.483 | -0.919 | 1.521 | -2.261 |
| 0.617     | 0.685 | 0.547 | -0.049 | 2.897 | -1.096 | 0.209 | -0.59 | 0.731 | -2.688 |
| 0.436     | 0.997 | -0.058 | 0.142 | 2.800 | -0.017 | -0.643 | -1.104 | 1.613 | -2.403 |
| 0.599     | 1.059 | 0.043 | -1.014 | 3.091 | -0.571 | -0.430 | -1.042 | 1.392 | -2.546 |
| 1.286     | 0.439 | 0.648 | -0.514 | 2.897 | -0.425 | -0.589 | -1.166 | 1.319 | -2.403 |
| 1.214     | 0.560 | 0.547 | -0.460 | 2.897 | -0.571 | -0.643 | -1.042 | 1.337 | -2.261 |
| 1.196     | 0.747 | 0.749 | -1.937 | 2.605 | 0.100 | -0.270 | -0.182 | 1.319 | -2.546 |
| 1.214     | 1.184 | 0.850 | -0.678 | 2.508 | 0.771 | -1.069 | -1.16 | 1.594 | -2.403 |

4.3. Relationship analysis

4.3.1. Relationship analysis clinker characteristics with strength clinker

This analysis is used to find out how the characteristic Clinker that will provide compressive strength that meets the standards. Evaluate the relationship between each component in Kiln Feeds with each component in Clinker; then the components are grouped in classes based on their Z value as table 6.

4.3.2. Relationship analysis regression relation characteristics kiln feeds with clinker characteristics

Regression analysis is used to see the correlation characteristic of Kiln Feeds with Clinker characteristics, so it is known how the characteristics of Kiln Feeds will produce the expected clinker
characteristics. Grouping the values of each oxide in the Feed and Clinker Kilns can be seen in the Table 7.

Table 6. Relation clinker characteristics with strength clinker

| Class KL SiO₂ | Class KL Al₂O₃ | Class KL Fe₂O₃ | Class KLMgO | Z Strength |
|---------------|----------------|---------------|-------------|------------|
| 1             | 1              | -1            | 1           | -3         | -0.460     |
| -2            | 3              | 1             | -1          | -1         | -0.084     |
| -2            | 2              | -1            | -1          | -2         | -1.149     |
| -1            | 1              | -2            | 1           | 1          | -0.397     |
| 2             | 3              | 1             | -1          | -1         | -0.710     |
| 1             | -1             | -1            | 2           | 2          | -0.543     |
| -1            | 2              | 1             | -2          | 2          | -0.334     |
| 1             | 1              | -1            | -2          | -1         | 1.295      |
| 1             | -2             | 1             | -1          | -1         | -1.149     |
| -1            | 2              | -1            | -1          | -1         | 0.481      |
| -1            | -1             | -4            | -1          | 1          | 0.355      |
| 2             | 2              | 3             | -2          | -1         | -1.463     |
| 2             | -3             | 1             | 1           | 1          | 2.361      |
| -3            | -2             | -1            | 2           | 1          | 0.543      |
| 1             | -1             | -1            | -1          | 2          | 0.167      |

Table 7. Group of SiO₂ value on folding and clinker kiln

| Class KF SiO₂ | Average KF.Z SiO₂ | Average KF.Z SiO₂ |
|---------------|-------------------|-------------------|
| -3            | -2.07             | -0.42             |
| -2            | -1.43             | -0.14             |
| -1            | -0.44             | -0.13             |
| 1             | 0.50              | 0.04              |
| 2             | 1.43              | 0.32              |
| 3             | 2.18              | 0.53              |

Table 8. Group of Al₂O₃ value on folding and clinker kiln

| Class KF Al₂O₃ | Average KF.Z Al₂O₃ | Average KF.Z Al₂O₃ |
|---------------|--------------------|--------------------|
| -3            | -2.481             | -0.313             |
| -2            | -1.325             | -0.334             |
| -1            | -0.472             | -0.018             |
| 1             | 0.534              | 0.013              |
| 2             | 1.349              | 0.377              |
| 3             | 2.274              | 0.915              |
### Table 9. Group of Fe₂O₃ value on folding and clinker kiln

| Class | Average KF Fe₂O₃ | Average KF.Z Fe₂O₃ |
|-------|-----------------|-------------------|
| -3    | -2.268          | -0.712            |
| -2    | -1.459          | -0.475            |
| -1    | -0.389          | -0.154            |
| 1     | 0.459           | 0.077             |
| 2     | 1.370           | 0.788             |
| 3     | 2.532           | 1.458             |
| 4     | 3.474           | 1.970             |

### Table 10. Group of CaO value on folding and clinker kiln

| Class | Average KF CaO | Average KF.Z CaO |
|-------|----------------|-----------------|
| -3    | -2.320         | -1.300          |
| -2    | -1.360         | -0.363          |
| -1    | -0.411         | -0.040          |
| 1     | 0.427          | 0.042           |
| 2     | 1.374          | 0.348           |
| 3     | 2.372          | 0.617           |
| 4     | 3.644          | 1.337           |

### Table 11. Group of MgO value on folding and clinker kiln

| Class | Average KF MgO | Average KF.Z MgO |
|-------|----------------|-----------------|
| -2    | -1.524         | -0.763          |
| -1    | -0.337         | -0.479          |
| 1     | 0.420          | -0.411          |
| 2     | 1.344          | -1.215          |
| 3     | 2.641          | -2.261          |
| 4     | 3.091          | -2.546          |

4.4. Linear programming formulas
The formulation of linear programming consists of determining decision variables, constraint functions, and objective functions.

4.4.1. Determination of decision variables
The decision variables in this raw material composition model are all the variables that the optimal solution is looking for for the basis of modeling, that is:

- \( X_i \) = The number of raw materials \( i \) used
- \( i \) = Type of raw material (1,2,3,4,5)

4.4.2. Function determination goals
The function of objectives to be achieved by the company is to minimize the cost of purchasing raw materials. Mathematically can be formulated as follows:

\[
\text{Minimize } Z = \sum_{i=1}^{5} C_i X_i
\]
where: \( X_i \) = Type of raw material (1,2,3,4,5)  
\( C_i \) = The cost of \( i \)-raw materials used per Ton.

### 4.4.3. Determination of function constraints

\[
T_{\text{min}} \leq \sum_{i=1}^{5} S_i X_i \geq T_{\text{max}} \tag{2}
\]

\[
U_{\text{min}} \leq \sum_{i=1}^{5} A_i X_i \geq U_{\text{max}} \tag{3}
\]

\[
V_{\text{min}} \leq \sum_{i=1}^{5} F_i X_i \geq V_{\text{max}} \tag{4}
\]

\[
W_{\text{min}} \leq \sum_{i=1}^{5} O_i X_i \geq W_{\text{max}} \tag{5}
\]

\[
Y_{\text{min}} \leq \sum_{i=1}^{5} M_i X_i \geq Y_{\text{max}} \tag{6}
\]

\[
\sum_{i=1}^{5} X_i = 1 \tag{7}
\]

\[
X_i \geq 0, i = 1,2,3,4,5 \tag{8}
\]

### 4.5. Model verification

Model verification is performed to check the mismatch of mathematical models with conceptual models. Verification of the model to be performed consists of:

#### 4.5.1. Dimension test

Verification of this model is done by performing a dimensional test by considering the similarity of dimensions (units) between the right and left sides in the mathematical model that has been formulated.

Minimize \( Z = \sum_{i=1}^{5} C_i X_i \) \( \tag{1} \)

\[
Rp = \left( \frac{R_p}{T\text{pm} \times \text{Toh}} \right)
\]

\[
R_p = R_p
\]

Based on equation (1) it is seen that the model dimension between the right and the left has the same. Thus, it can be concluded that the designed mathematical model has been verified and can be used.

#### 4.5.2. Test of constraint fulfillment
The constraint-fulfillment test is done by manual count for Solver output. Here are the results of manual calculations:

\[ T_{\text{min}} \leq (S_1X_1 + S_2X_2 + S_3X_3 + S_4X_4 + S_5X_5) \]
\[ 0,11 \leq ((0,1014 \times 0,89) + (0 \times 0) + (0,7440 \times 0,016) + (0,2587 \times 0) + (0,4202 \times 0,085)) \]
\[ 0,11 \leq 0,139(\text{corresponding}) \]

\[ T_{\text{max}} \geq (S_1X_1 + S_2X_2 + S_3X_3 + S_4X_4 + S_5X_5) \]
\[ 0,172 \geq ((0,1014 \times 0,89) + (0 \times 0) + (0,7440 \times 0,016) + (0,2587 \times 0) + (0,4202 \times 0,085)) \]
\[ 0,172 \geq 0,139(\text{corresponding}) \]

\[ U_{\text{min}} \leq (A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4 + A_5X_5) \]
\[ 0,029 \leq ((0,0166 \times 0,89) + (0 \times 0) + (0,1552 \times 0,016) + (0,0722 \times 0) + (0,294 \times 0,085)) \]
\[ 0,029 \leq 0,043(\text{corresponding}) \]

\[ U_{\text{max}} \geq (A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4 + A_5X_5) \]
\[ 0,043 \geq ((0,0166 \times 0,89) + (0 \times 0) + (0,1552 \times 0,016) + (0,0722 \times 0) + (0,294 \times 0,085)) \]
\[ 0,043 \geq 0,043(\text{corresponding}) \]

\[ V_{\text{min}} \leq (F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5) \]
\[ 0,02 \leq ((0,0107 \times 0,89) + (0 \times 0) + (0,014 \times 0,016) + (0,4878 \times 0) + (0,1168 \times 0,085)) \]
\[ 0,02 \leq 0,02(\text{corresponding}) \]

\[ V_{\text{max}} \geq (F_1X_1 + F_2X_2 + F_3X_3 + F_4X_4 + F_5X_5) \]
\[ 0,026 \geq ((0,0107 \times 0,89) + (0 \times 0) + (0,014 \times 0,016) + (0,4878 \times 0) + (0,1168 \times 0,085)) \]
\[ 0,026 \geq 0,02(\text{corresponding}) \]

\[ W_{\text{min}} \leq (O_1X_1 + O_2X_2 + O_3X_3 + O_4X_4 + O_5X_5) \]
\[ 0,04 \leq ((0,4697 \times 0,89) + (0 \times 0) + (0,0102 \times 0,016) + (0,0331 \times 0) + (0,0093 \times 0,085)) \]
\[ 0,04 \leq 0,423(\text{corresponding}) \]

\[ W_{\text{max}} \geq (O_1X_1 + O_2X_2 + O_3X_3 + O_4X_4 + O_5X_5) \]
\[ 0,0457 \geq ((0,4697 \times 0,89) + (0 \times 0) + (0,0102 \times 0,016) + (0,0331 \times 0) + (0,0093 \times 0,085)) \]
\[ 0,0457 \geq 0,423(\text{corresponding}) \]

\[ Y_{\text{min}} \leq (M_1X_1 + M_2X_2 + M_3X_3 + M_4X_4 + M_5X_5) \]
\[ 0,002 \leq ((0,0048 \times 0,89) + (0 \times 0) + (0,0063 \times 0,016) + (0,0082 \times 0) + (0,0033 \times 0,085)) \]
\[ 0,002 \leq 0,005(\text{corresponding}) \]
\[ Y_{\text{min}} \geq (M_1X_1 + M_2X_2 + M_3X_3 + M_4X_4 + M_5X_5) \]
\[ 0.008 \geq ((0.0048 \times 0.89) + (0 \times 0) + (0.0063 \times 0.16) + (0.0082 \times 0) + (0.0033 \times 0.85)) \]  
\[ 0.008 \geq 0.005 \text{(corresponding)} \]  

4.5.3. Model validation  
Validation stage is done by face validity technique to output model with Laboratory staff.  

5. Implementation and analysis of model  
Development of mathematical models using the relationship of regression and linear programming.  

5.1. Implementation model  

| Table 12. Raw Material Content Data | SiO\(_2\) | Al\(_2\)O\(_3\) | Fe\(_2\)O\(_3\) | CaO | MgO |
|-----------------------------------|---------|----------------|----------------|-----|-----|
| Limestone                         | 0.0440  | 0.0100         | 0.0078         | 0.590 | 0.0047 |
| Silica                            | 0.6690  | 0.1234         | 0.0571         | 0.031 | 0.0051 |
| Pozzolan                          | 0.0000  | 0.0000         | 0.0000         | 0.000 | 0.0000 |
| Iron sand                         | 0.1900  | 0.0400         | 0.5800         | 0.080 | 0.0040 |
| Clay                              | 0.4359  | 0.2800         | 0.1100         | 0.009 | 0.0034 |
| Composition required (%)          |         |                |                |      |      |
| Minimum                           | 0.110   | 0.029          | 0.020          | 0.0409 | 0.002 |
| Maximum                           | 0.157   | 0.043          | 0.028          | 0.440  | 0.010 |

By using Microsoft, Excel Solver obtained results in Table 13.  

| Table 13. Raw material content data by the solver | Limestone (X\(_1\)) | Silica (X\(_2\)) | Pozzolan (X\(_3\)) | Iron sand (X\(_4\)) | Clay (X\(_5\)) | Usage |
|-------------------------------------------------|--------------------|------------------|--------------------|---------------------|----------------|-------|
| SiO\(_2\)                                        | 0.0440             | 0.6690           | 0.0000             | 0.1900              | 0.4359         | 0.1100 |
| Al\(_2\)O\(_3\)                                  | 0.0100             | 0.1234           | 0.0000             | 0.0400              | 0.2800         | 0.0428 |
| Fe\(_2\)O\(_3\)                                  | 0.0078             | 0.0571           | 0.0000             | 0.5800              | 0.1100         | 0.0204 |
| CaO                                             | 0.5090             | 0.0311           | 0.0000             | 0.0800              | 0.0090         | 0.4376 |
| MgO                                             | 0.0047             | 0.0051           | 0.0000             | 0.0040              | 0.0034         | 0.0046 |

By using regression of characteristic relationship of Kiln Feed with Clinker characteristic, it can be predicted the characteristics of SiO\(_2\), Al\(_2\)O\(_3\), Fe\(_2\)O\(_3\), CaO, and MgO on Clinker. Based on the results of Table 10 and Table 11 it can be predicted that the characteristics of Z- SiO\(_2\), Z- Al\(_2\)O\(_3\), Z- Fe\(_2\)O\(_3\), Z- CaO of value 1, will produce a range of Z-Strength between 242-248, and Z-MgO a value of -1 will result in a range of Z-Strength between 228-238  

5.2. Price comparison of silica with pozzolan  
By using Microsoft Excel Solver we can compare the composition of the material at table 3 and table 14, solver solution will be:
Table 14. Value of decision variables and raw material purchase costs using silica

|             | Limestone (X₁) | Silica (X₂) | Pozzolan (X₃) | Irond Sand (X₄) | Clay (X₅) |
|-------------|----------------|-------------|---------------|----------------|-----------|
| Decision Variable | 0.855          | 0.040       | 0.0000        | 0.1900         | 0.105     |
| Total Cost (ton)  | 42,249.81 Rp/ton |

Table 15. Value of decision variables and raw material purchase costs using pozzolan

|             | Limestone (X₁) | Silica (X₂) | Pozzolan (X₃) | Irond Sand (X₄) | Clay (X₅) |
|-------------|----------------|-------------|---------------|----------------|-----------|
| Decision Variable | 0.899          | 0.000       | 0.016         | 0.000          | 0.0805    |
| Total Cost (ton)  | 42,515.55 Rp/ton |

6. Conclusion and recommendations
1. From the results of data processing research obtained a regression model that can be used to predict clinker characteristics based on raw material characteristics.
2. Formulation of the optimization model of raw material composition which will give the lowest cost based on the content of each raw material analyzed.
3. The results of raw material optimization provide information that the use of pozzolan as a substitute for silica increases raw material costs about 265.74 Rp/ton raw material.

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