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# Investigation of Filtration Variables on Moisture Control in Iron Ore Concentrate for Pelletization

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## Abstract

*The moisture content in the final cake should be 10~11% for optimum ball formation in the iron ore pellet making. The situation arises from the beneficiation plants, where the moisture percentage of the final cake varies due to several factors. The findings of this comprehensive study are of significant importance to the iron ore processing industry. The study meticulously investigated the impact of essential filtration parameters like feed density, hold time, and filtration pressure on the final cake moisture. Experiments were conducted on industrial VPA filters at the ore beneficiation plant, a unit of JSW Steels Toranagallu, Sandur Karnataka, India. A response surface experiment was developed using the Minitab statistical tool for a vertical pressure filter to examine the influence of selected variables on the moisture content of the iron ore concentrate. The results show that increased pressure and feed density led to a reduction in cake moisture. The optimum moisture content of 9.52% was achieved with a feed density of 1.6 g/cc, filtration pressure of 12 bar, and a hold time of 4minutes.*

***Major Findings:*** *Optimised industrial VPA filter performance using MINITAB response optimiser to minimise moisture percentage. Achieved minimum moisture content of 9% by optimizing feed density (1.6g/cc), filtration pressure (12bar), and hold time (4min). Composite desirability value of 0.96 confirms optimal process variable settings.*

**Keywords:** *Filtration, Iron Ore, Minitab, Optimization*

## 1.0 Introduction

The standalone pellet plants operate the beneficiation plants with the pellet production. The premium pellets produced by the standalone pellet plants must undergo several quality tests for market suitability[1-5]. The Indian standalone pellet plants are facing multiple challenges regarding the quality of the raw material, especially low-grade iron ore, which requires fine grinding[6-7]. The heterogeneity in ore supply combined with complex mineralogy has made beneficiating difficult.The pellet plant operational parameters, such as particle size-specific surface area, are controlled by grinding units, whereas moisture must be controlled during the filtration of the ground products. Filtration is one of the significant dewatering processes in mineral processingoperations because most beneficiation processes are conducted in the wet process[7-9]. The pressure press filtration method has gained much importance in iron ore processing because of its effectiveness and high throughput. The dewatering of pelletizing feed needs careful attention to produce quality pellets with appropriate moisture levels[9-15]. Vertical pressure filters have gained much importance in iron ore concentrate filtration solutionsbecause of their varied capacity. The thick slurry ofiron ore concentrate is collected from the concentrate thickeners of the pellet plant in the Sandur area, Karnataka, India. The study aims to build a relationship between the chosen variables

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of the vertical pressure filter(VPA), such as air pressure, feed rate, feed density, and air blowing time,on the final moisture content of pellet feed.The filter cloth product was characterized for moisture and cake thickness for each filtration test. The VPA performance is analyzed using the statistical software MINITAB 16 (trial version).

# 2.0 Experimental

## 2.1 Sample

The iron ore concentratesslurry samplingwas done at the concentrate thickener of the ore beneficiation plant, a unit of JSW Steels near Sandur, Karnataka, India. The wet sieve analysis of the slurry sample indicates that 80% of the particles were passing 75 microns Figure 1.Table 2shows the chemical analysis; the total Fe content is around 62%, and the specific gravity of the sample is 3.8 gm/cc.

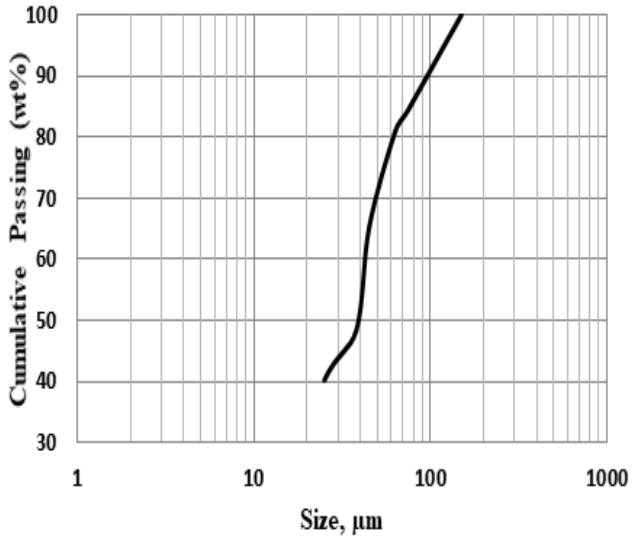



**Figure 1.** Sieve analysisof filtration feed.

## 2.2 Design of Experiment

Response Surface Methodology (RSM) is a collection ofstatistical and mathematical methods useful for modelling and analyzing problems. This technique's main objective is to optimize the response surface influenced by various process parameters. The RSM also quantifies the relationship between the controllable input parameters and the response surfaces.To determine the relationship between the independent and dependent variables, the data collected were subjected to regression analysis using the response surface regression procedure of MINITAB. Regression analysis models a response factor (Y*i*) as a mathematical function of a few continuous factors. Each response (Y*i*) was represented by a mathematical equation that correlates the response surfaces. The response was then expressed as a second-orderpolynomial equation according to Equation (1).

$$Yi = f(y) = \beta_0 + \sum_{i=1}^{K} \beta_i x_i + \sum_{i=1}^{K} \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

Where Y*i* is the predicted response related to theindependent variable, *k* is the number of independentvariables (factors) shown in Table 1. Xi (i = 1, 2, 3); while *β*is a constant coefficient βi, βij, and βii the coefficients of linear, interaction, and square terms, respectively, and ε is therandom error term.

A second-order polynomial equation was chosen to fit theexperimental results. This model represents the effects ofprocess variables (A, B, C) and their interactions on theresponse variables (% Moisture). The generalform of the model chosen is represented as follows.

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 \quad (2)$$

**Table 1.**Chemical analysis data of iron ore sample

| Fe | $SiO_2$ | $Al_2O_3$ | MnO | MgO | $Na_2O$ | $TiO_2$ | LOI |
|---|---|---|---|---|---|---|---|
| 62.1 | 2.98 | 3.44 | 0.09 | 0.03 | 0.04 | 0.31 | 4.12 |

Where Y is the predicted response, b0 is model constant; b1, b2, and b3 are linear coefficients; b12, b13, b23 are cross-product coefficients, and b11, b22, b33 are the quadraticcoefficients. Statistical software MINITAB was used to estimate the coefficients.

### *2.2.1 Filtration Tests*

A systematic, statistically designed set of experiments was meticulously conducted to analyze the VPA performance for iron ore concentrate filtration. Batch filtration tests were performed on the iron ore slurry to know the effects of chosen parameters on filtration performance. Fifteen sets of experiments were performed as per the Box Bhenken design using varying pulp density, feed pressure, and pressure holding time. The levels of the process variables were

**Table 2.**Levels of the process variables of the filtration test

| Parameters | Units | Low (-1) | High (+1) |
|---|---|---|---|
| Feed Density | g/cc | 1.30 | 1.90 |
| Filter Pressure | bar | 1.50 | 12.0 |
| Hold Time | min | 4 | 12.0 |

**Table 3.**Experimental design

| Experimental Run | (A) | (B) | (C) |
|---|---|---|---|
| | Feed Density(g/cc) | Filtretion Pressure(bar) | Hold time (min) |
| 1 | 1.30 | 1.50 | 8.00 |
| 2 | 1.90 | 1.50 | 8.00 |
| 3 | 1.30 | 12.00 | 8.00 |
| 4 | 1.90 | 12.00 | 8.00 |
| 5 | 1.30 | 6.75 | 4.00 |
| 6 | 1.90 | 6.75 | 4.00 |
| 7 | 1.30 | 6.75 | 12.00 |
| 8 | 1.90 | 6.75 | 12.00 |
| 9 | 1.60 | 1.50 | 4.00 |
| 10 | 1.60 | 12.00 | 4.00 |
| 11 | 1.60 | 1.50 | 12.00 |
| 12 | 1.60 | 12.00 | 12.00 |
| 13 | 1.60 | 6.75 | 8.00 |
| 14 | 1.60 | 6.75 | 8.00 |
| 15 | 1.60 | 6.75 | 8.00 |

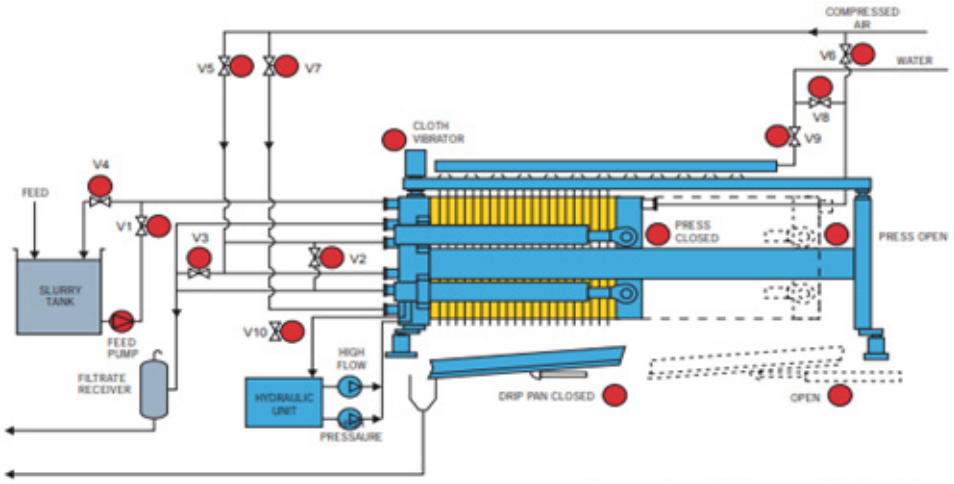



**Figure 2.** Circuit diagram of verticle pressure filter.

tabulated in Table 3. The cake was analyzed for % moisture by drying it in an electric oven at 105°Cto evaluate the effect of process parameters on cake moisture.

# 3.0 Results and Discussions

## 3.1 Statistical Analysis

The moisture percentages observed from the industrial

**Table 4.** Results of statistical design of experiments

| Experimental Run | (A) | (B) | (C) | % Moisture | |
|---|---|---|---|---|---|
| | Feed Density(g/cc) | Filtretion Pressure(bar) | Hold time (Sec) | Observed | Predicted |
| 1 | (-1) | (-1) | (0) | 14.94 | 15.16 |
| 2 | (+1) | (-1) | (0) | 13.65 | 13.85 |
| 3 | (-1) | (+1) | (0) | 12.84 | 12.64 |
| 4 | (+1) | (+1) | (0) | 13.00 | 12.78 |
| 5 | (-1) | (0) | (-1) | 13.12 | 13.14 |
| 6 | (+1) | (0) | (-1) | 12.69 | 12.74 |
| 7 | (-1) | (0) | (+1) | 12.90 | 12.85 |
| 8 | (+1) | (0) | (+1) | 12.10 | 12.08 |
| 9 | (0) | (-1) | (-1) | 12.84 | 12.60 |
| 10 | (0) | (+1) | (-1) | 9.64 | 9.82 |
| 11 | (0) | (-1) | (+1) | 11.31 | 11.14 |
| 12 | (0) | (+1) | (+1) | 10.09 | 10.33 |
| 13 | (0) | (0) | (0) | 11.00 | 11.00 |
| 14 | (0) | (0) | (0) | 11.00 | 11.00 |
| 15 | (0) | (0) | (0) | 11.00 | 11.00 |

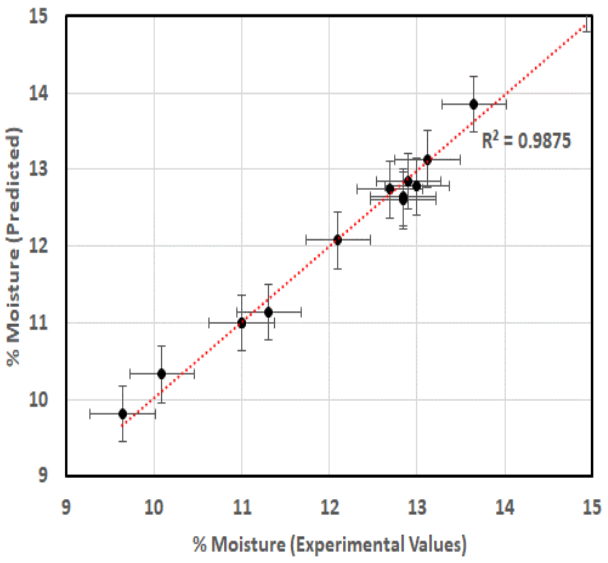



**Figure 3.** Predicted and actual moisture values of VPA filter.

scale VPA operations were rigorously analyzed using advanced statistical tools such as MINITAB 17.0.0 (trial Version). A set of 15 runs was carried out by varying feed density (A), filtration pressure (B), and Hold time (c) following the complete factorial design of experiments. Statistical analysis tools such as ANOVA and regression equations have been proposed for the response variables. The Analysis of Variance (ANOVA) method was adopted to evaluate the primary and interactional effects of the variables on the responses. Table 5 depicts the ANOVA results on the % moisture.

The order of significance of the primary variables on the %moistureis B > A > C. Similarly, the order of importance among the variables' interactions is A.B.> A.C.> B.C. A second-order polynomial equation is developed to fit the experimental results. This model represents process variables (A, B, C) and their interactions with the response variables (% moisture).

$$\% \text{ Moisture} = 77.55 - 79.08\ A - 0.942\ B + 0.373\ C + 24.11\ A^2 + \mathbf{0.01587\ B^2} - 0.02922\ C^2 + 0.2302\ A*B - 0.077\ B*C + 0.02357\ A*C \quad (3)$$

Equations (3) could be used to predict the % moisture for the VPA Filter to any unknown variables that fall within the Study range of the present investigation. The response values of the % moisture are predicted using the model equation (Equations (3)) and compared with

**Table 5.** Anova table on moisture percentage

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Feed Density (g/cc)(A) | 1 | 0.6962 | 0.6962 | 9.7 | 0.026 |
| Filtretion Pressure (bar)(B) | 1 | 6.4261 | 6.4261 | 89.51 | 0.001 |
| Hold time(C) | 1 | 0.4465 | 0.4465 | 6.22 | 0.055 |
| A*A | 1 | 17.3867 | 17.3867 | 242.17 | 0.001 |
| B*B | 1 | 0.7067 | 0.7067 | 9.84 | 0.001 |
| C*C | 1 | 0.807 | 0.807 | 11.24 | 0.026 |
| A*B | 1 | 0.5256 | 0.5256 | 7.32 | 0.02 |
| A*C | 1 | 0.0342 | 0.0342 | 0.48 | 0.029 |
| B*C | 1 | 0.9801 | 0.9801 | 13.65 | 0.042 |
| Lack-of-Fit | 3 | 0.359 | 0.1197 | | |

the experimental data. The significance of the models is described in different ways, and the results are given in Table 5. From Table 5, it is clear that all the statistical terms for these models are within the limits of reliable statistics. The model prediction values for the adsorption responses closely match the experimental data. Furthermore, the influence of operating variables on % moisture is analyzed using three-dimensional (3D) response surface plots. These plots help show the functional relationship between the response and three independent variables. The experimental results and the predicted values obtained using model Equation (3) are shown in Table 4 and Figure 3. The predicted and the observed data point relationship indicates that the % moisture model has agreed well ($R^2$ of 0.98) with the response equation.

## 3.2 Effect of Process Variables on % Adsorption

Filtered cake moisture of the VPA filter is determined as a function of selected variables like feed density, pressure, and hold time. The difference between the oven calculated the % moisture dried cake and the filtered cake, and the moisture percentage is expressed. The results are plotted in a 3D surface plot to identify the effect of each process variable, like feed density, filtration pressure, and hold time. Figure 4(a)shows that % moisture declined as the filtration pressure increased at feed density 1.6, and the optimum moisture was achieved. Further, with an increase in the feed density, the moisture values reached the maximum values, attributing to an increase in shear stress and the flow becoming dilatant. Figure 4(b)shows

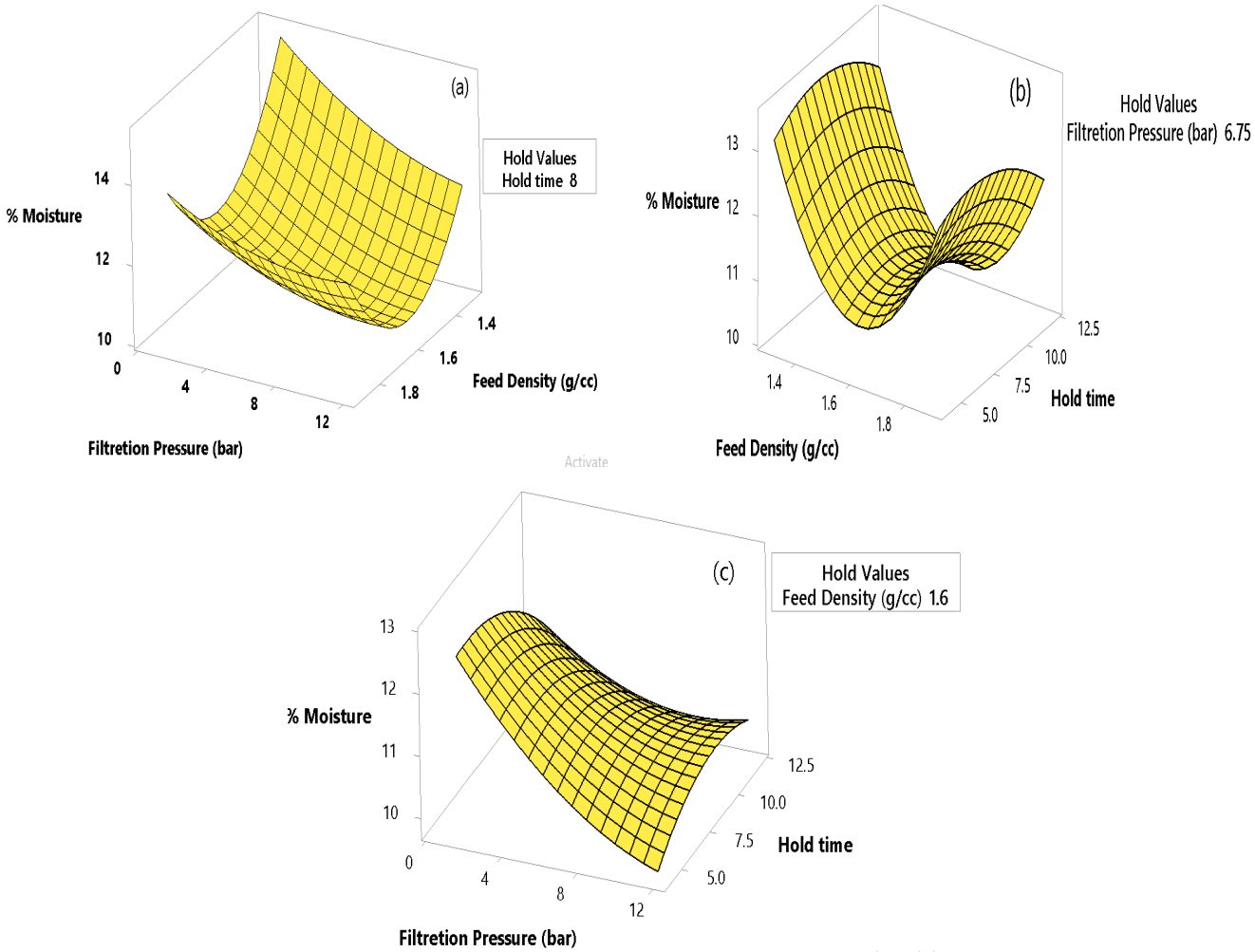



**Figure 4.** **(a)** effect of filtration pressure and feed density on % moisture.**(b)** Effect of feed density and hold time on % moisture.**(c)** Effect of filtration pressure and hold time.

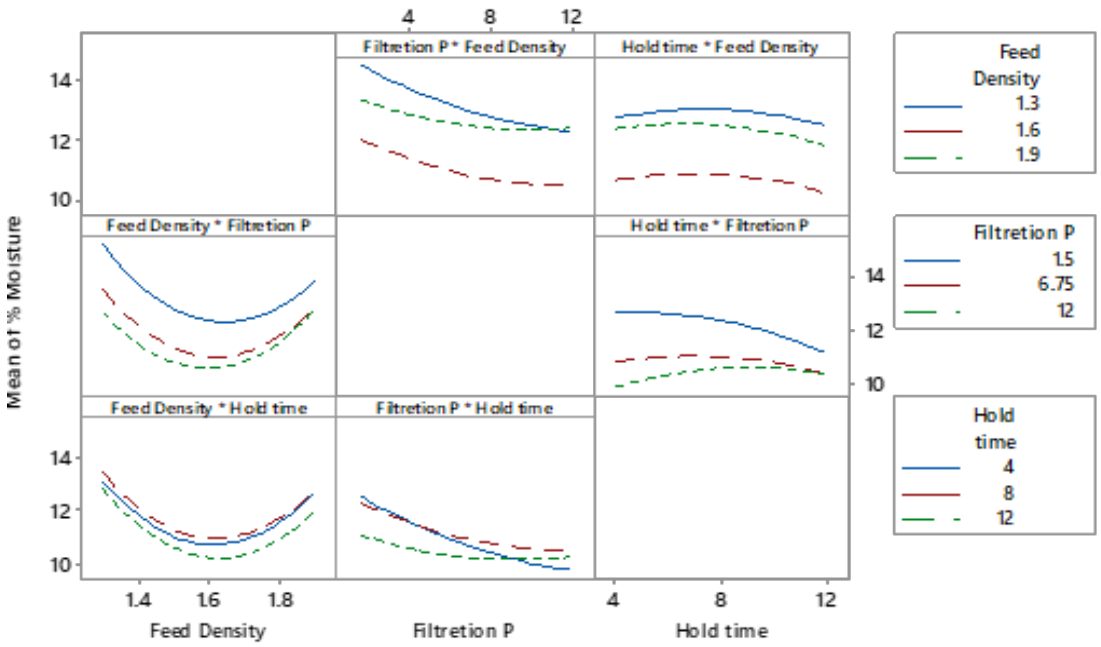



**Figure 5.** Interaction plots of variables on response.

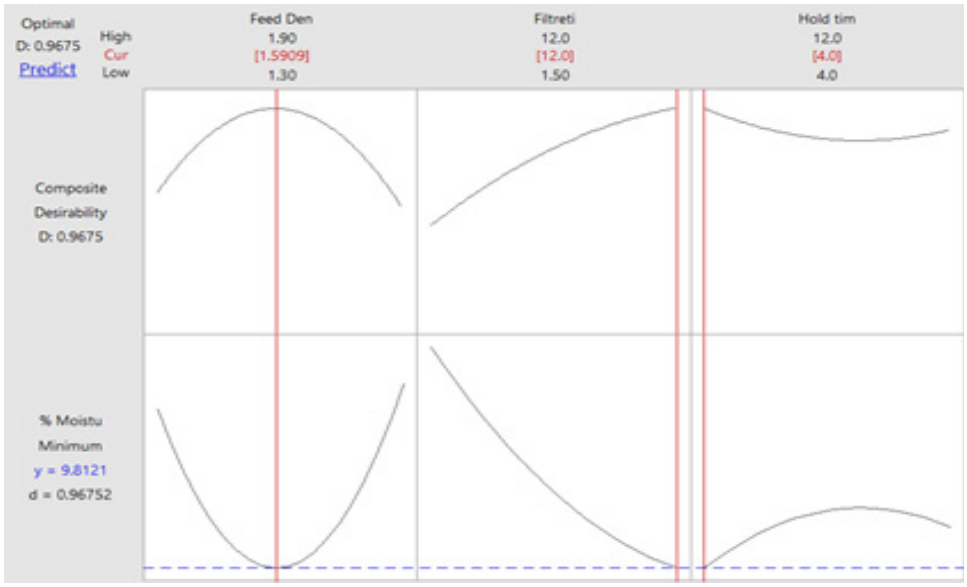



**Figure 6.** Optimization chart for % moisture.

the effect of feed density and hold time on the final % moisture of the VPA Filter; it is observed that the % moisture is decreasing at a medium level of 8min at a feed density of 1.6 g/cc. Figure 4(c) depicts that the % moisture is consistently reducing as the filtration pressure increases, and the minimum moisture is reported as 9% at a feed density of 1.6 g/cc, filtration pressure of 12 bar with a minimum hold time of 4 min. the interaction of variables in optimizing of response (moisture) is shown in Figure 5.

### 3.3 Optimization Studies

Optimization studies on %moisture for an industrial VPA Filter, using a MINITAB response optimizer, are studied here. The key features of the response optimizer tool of MINITAB identify the combination of input variable settings that optimize a single response or a set of reactions by satisfying the requirements for each response in the collection. The optimization was accomplished by:

a. Obtain the individual desirability (d) for each response;
b. Combine the individual desirability to obtain combined or composite desirability (D);
c. Maximize the composite desirability and identify the optimal input variable settings.

This study's main objectives are to optimize feed density, filtration pressure, and hold time to produce a minimum moisture percentage. In optimization, the goal is to minimize the response obtained from the experimental results. The figure depicts the optimization value of all of the responses.

Based on the response analysis of an industrial VPA filter, a minimum moisture content of 9% of pellet concentrate cake could be achieved by optimizing the process variables at a feed density of 1.6g/cc, filtration pressure of 12bar, and a hold time of 4 min. The composite desirability value at the optimum design is 0.96, as shown in Figure 6.

## 4.0 Conclusion

The ore feed to the beneficiation plants is heterogeneous, leading to the final concentrate and moisture variation. Moisture is an essential factor in pellet making. The optimum moisture of filtered cake not only improves large-scale pellet production but also improves the pellet strength. This study aims to assess the effectiveness of an industrial VPA filter for final cake moisture. Statistically, designed experiments were conducted to understand the influence of feed density, filter pressure, and hold time on the final cake moisture. The moisture percentage in the filtered cake is achieved to the minimum value of 9% at a feed density of 1.6g/cc, filter pressure of 12 bar with 4min of hold time. The tests' statistical significance was also validated by comparing the experimental and predicted moisture values. The optimization tool of MINITAB software shows the composite desirability value of 0.96, which represents the concurrency of the developed model in good agreement with the experimental values.

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