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Evaluation and Comparison of the Effect of Adding Pulverized and Unpulverized Rice Husk into Water-Based Drilling Mud on Rheological Properties Along with Presentation of an Artificial Neural Network Model

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Abstract

The rheological properties of drilling fluids are essential parameters in optimizing drilling operations and reducing the total cost of drilling. The effect of adding herbal polymers of pulverized and unpulverized rice husk on the amount of shear stress of water-based drilling mud at different shear rates has been investigated and compared. After determining the plastic viscosity (PV) and yield point (YP) of the samples based on the Bingham model, no uniform trend was observed in the changes in the rheological properties of the drilling mud with the increase in the mass of each additive to the base fluid. A model based on a two-layer feedforward artificial neural network is designed to predict the shear stress of the studied drilling muds, and the network was trained for each set of data, which resulted in accurate estimation results. The percentage of average and maximum error obtained for the output values corresponding to the network test data is smaller compared to the results of applying the widely used Herschel-Bulkley model. Moreover, we found through sensitivity analysis that the importance and degree of influence of the shear rate on changes in shear stress are higher compared to the additive mass.

Keywords: Pulverized rice husk, Unpulverized rice husk, Rheological properties, Shear rate, Two-layered feedforward artificial neural network

1. Introduction

Drilling mud is a viscous and dense fluid used in drilling operations for hydrocarbon-bearing reservoirs. Drilling fluids exist in various forms, including oil-based, water-based, and synthetic-based muds. Among these, oil-based and water-based drilling fluids are the most widely used in the petroleum industry [1]. The rheology of drilling fluids refers to the science of deformation and flow of matter. Rheological properties—such as plastic viscosity (PV), yield point (YP), and apparent viscosity—significantly influence drilling fluid performance and the overall efficiency of drilling operations [2-5]. Accordingly, the use of drilling fluid additives that do not damage the formation and are also cost-effective is of great importance [6].

The influence of rice husk on improving the rheological properties—and consequently the overall performance—of drilling mud has been investigated in only a limited number of previous studies. For instance, Zarei and Nasiri [7] examined the modification of drilling fluid rheology in the presence of silica oxide nanoparticles combined with rice husk. Their results demonstrated that these nanoparticles, when blended with rice husk, can serve as an effective additive for enhancing the rheological properties of water-based drilling fluids. Akinyemi and Abdulhadi [8] studied the effects of temperature on the rheological behavior of bentonite-based drilling fluid containing rice husk additives and concluded that rice husk acts as a viscosity enhancer, improving mud viscosity under elevated temperatures. Peter and Olamilekan [9] conducted a comparative analysis of rice husk and xanthan gum as viscosity enhancers in water-based drilling fluids. They explored the feasibility of substituting rice husk for xanthan gum and found that rice husk can indeed serve as a viscosity-increasing agent in such fluids, though a greater amount of rice husk is needed compared to xanthan gum to achieve similar results.

The principal objective of the present study is to measure the shear stress of a water-based drilling mud after adding different masses (0.5, 1, 2, and 3 grams) of each natural polymer—both powdered and unpowdered rice husk—to the base mud at various shear rates (corresponding to rotational speeds of 3, 6, 100, 200, and 300 revolutions per minute). Based on the Bingham rheological model, the PV and YP of the samples were then calculated, and the results were compared for each additive, considering the mass of the natural polymer added to the drilling fluid. Furthermore, to estimate the shear stress of the drilling fluid for any desired input mass of plant polymer and shear rate, a predictive two-layer feedforward artificial neural network (ANN) model was developed and trained using available experimental data. The proposed intelligent model demonstrates high accuracy in predicting the shear stress of drilling mud. In addition, the performance of the developed neural network models was compared with the widely used Herschel–Bulkley rheological model in describing the relationship between shear stress and shear rate in drilling fluids.

2. Methodology

All drilling mud samples were prepared in the drilling fluid laboratory in accordance with the API Standards. The water-based drilling mud sample used in this study consisted of a mixture of 350 cc of water and 15 g of bentonite. During various experimental stages, different masses (0.5, 1, 2, and 3 g) of both powdered and unpowdered rice husk polymers were separately added to the base mud. The mixing and stirring process was continued in a mixer until a stable mud was obtained. To measure the shear stress as a function of shear rate, a Fann Model 35 rotational viscometer was employed at the rotational speeds of 3, 6, 100, 200, and 300 rpm of the outer cylinder. The variation of shear stress in the drilling fluid with increasing amounts of powdered rice husk did not follow a consistent trend. In contrast, increasing the mass of unpowdered rice husk in the drilling fluid generally led to higher shear stress values, indicating the favorable effect of this additive on the rheological properties of the drilling fluid.

To develop a predictive model for estimating the shear stress of drilling mud samples containing each type of rice husk additive (powdered and unpowdered), two feed-forward ANNs with two layers and ten neurons in the hidden layer were configured, trained, and tested using MATLAB software (Figure 1).

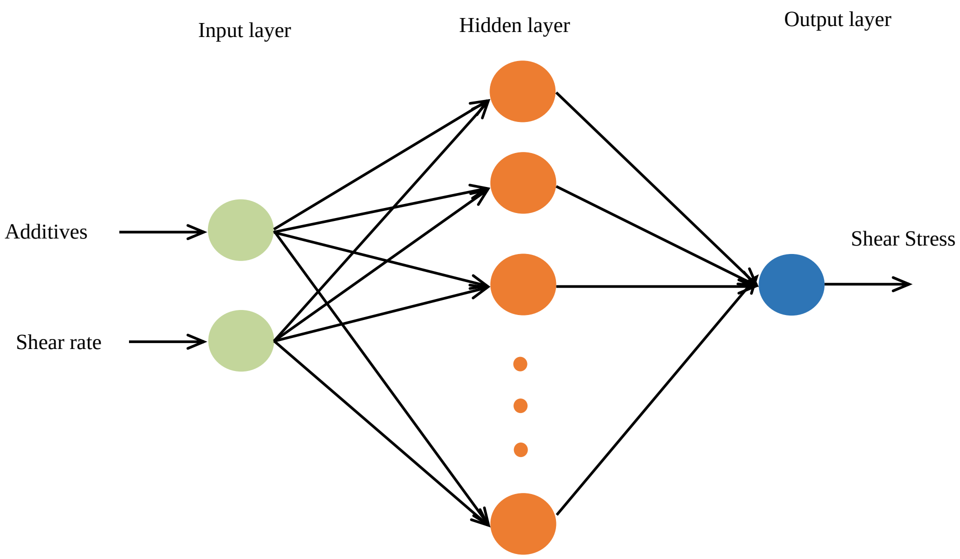

Figure 1. Schematic architecture of the back-propagation ANN used for estimating the shear stress of the drilling fluid

Discussion and Results

Corresponding to each additive mass value, the shear stress of the fluid containing powdered rice husk was lower than that of the fluid containing non-powdered rice husk at lower shear rates, and higher at higher shear rates (with the exception of the fluid containing 3 g of additive). Overall, the yield stress and PV of the drilling mud exhibited different variation trends depending on the rice husk form. With increasing mass of powdered rice husk, the yield stress showed an oscillatory trend, while the PV followed an increasing–decreasing trend. In contrast, with increasing mass of non-powdered rice husk, the yield stress showed an increasing–decreasing trend, and the PV a decreasing–increasing trend. For the fluid containing powdered rice husk, the lowest YP corresponded to the highest PV (for 1 g additive in the base fluid), whereas the highest YP corresponded to the lowest PV (for 2 g additive in the base fluid). For the fluid containing non-powdered rice husk, the lowest YP corresponded to the highest PV (for the base fluid without any additive), and the highest YP corresponded to the lowest PV (for 2 g additive in the base fluid).

Based on the results obtained from the Bingham model, when either of these natural polymers is added to the drilling fluid, only one rheological property—either yield stress or PV—can be improved. Simultaneous enhancement of both properties using these additives is not attainable. Furthermore, comparison of the effects of these natural polymers indicates that, in general, the addition of non-powdered rice husk leads to better improvement in yield stress, whereas the addition of powdered rice husk more effectively enhances PV, both contributing to improved rheological behavior of the drilling mud.

The correlation coefficients for the training, validation, and testing datasets, as well as for the total dataset of the ANN corresponding to powdered rice husk, were 1.0000, 0.99427, 0.99425, and 0.99847, respectively. For the ANN corresponding to non-powdered rice husk, the values were 0.99872, 0.99178, 0.98887, and 0.99568. This demonstrates that the designed ANN models are capable of predicting the shear stress of drilling mud samples containing different additive masses at various shear rates with very high accuracy.

The relative error percentage plots between the actual values and the outputs of the trained ANN, as well as between the actual values and the results of the Herschel–Bulkley model for the test data of drilling muds containing powdered and non-powdered rice husk polymers, are presented in Figures 2-3, respectively.

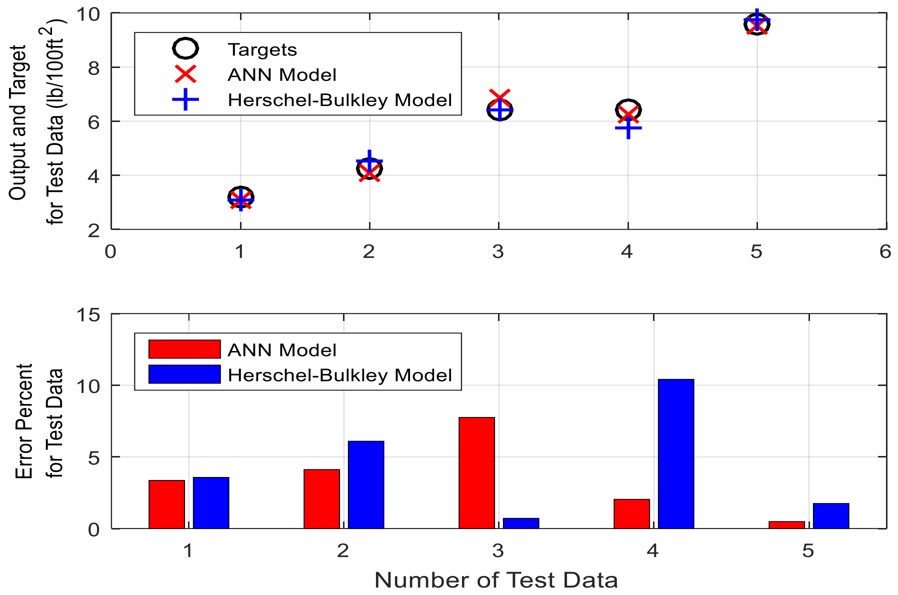

Figure 2. The relative error percentage plots between actual values and outputs of the ANN model and the Herschel–Bulkley model for test data of drilling mud containing powdered rice husk

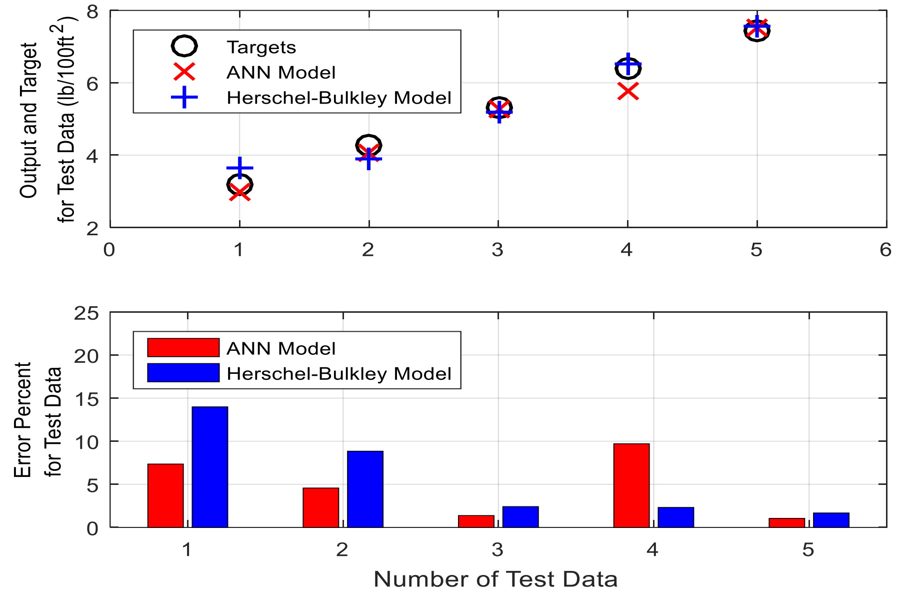

Figure 3. The relative error percentage plots between actual values and outputs of ANN model and the Herschel–Bulkley model for test data of drilling mud containing non-powdered rice husk

3. Conclusions

1) Increasing the mass of powdered rice husk in the base mud does not lead to a specific trend in the fluid's shear stress. However, increasing the mass of unpowdered rice husk in the drilling fluid generally results in an increase in the mud's shear stress.

2) The yield stress and PV of the drilling mud, with an increase in the amount of powdered rice husk, exhibit a fluctuating trend and an increasing-decreasing trend, respectively. With an increase in the amount of unpowdered rice husk, they show an increasing-decreasing trend and a decreasing-increasing trend, respectively.

3) By comparing the effects of adding these herbal polymers, it can be concluded that, adding unpowdered rice husk is effective in improving the rheological behavior of the drilling mud by increasing the yield point. Similarly, adding powdered rice husk improves the rheological behavior by increasing the PV.

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