



PRODUCTION OF A NOVEL BIO-POLYMER FOR ENHANCED OIL RECOVERY AND MODELLING THE POLYMER VISCOSITY USING ARTIFICIAL NEURAL NETWORK (ANN)

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ABSTRACT

This research introduces a novel biopolymer that can be used for enhanced oil recovery (EOR) applications. Starch biopolymer was produced from potato peels (a means of turning waste to wealth as well as a viable alternative approach to chemically synthesized polymers). The assessment of EOR applicability of the biopolymer produced was carried out. The results showed that biopolymer produced has good pore-plugging abilities, relative thermal stability, insensitivity to presence of NaCl and good rheological properties up shear rates of to 300 rpm. ANN model was developed to adequately fit the interaction between the three process variables (polymer concentration, salt concentration, shear rate) and the response (polymer viscosity). The results showed that the model had R^2 of 0.995 and negligible error (mean square error, MSE, of 0.01419).

Keywords: ANN Modelling, Biopolymer, Enhanced Oil Recovery, Potato Starch.

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1. INTRODUCTION

Petroleum products remain the major sources of energy globally [1-3]. These products serve as pivot to the global economy today due to the increasing demand for energy as a result of the growing human population, life style changes of the people and improvement in technology. According to the Organization of Petroleum Exporting Countries (OPEC), the demand for oil increased from 86.97 Million Barrels of oil per day (BOPD) in June 2011 to 88.42 BOPD in June 2012, from 94.18 BOPD in March 2016 to 96.16 BOPD in September 2016 and a forecasted increase in demand to 107 million BOPD in 2035 [4-5]. However, since 1995, oil production has been declining due to shortage of current oil resources and difficulties in identifying new reserves. To meet the continuously increasing demand for oil demand and sustain supply, there is a need to maximize the extraction of the original oil in place (OOIP) from the existing oil reservoirs [5-6]

Oil and gas production life of hydrocarbon fields are divided into phases. In the initial stage (primary recovery), oil and gas production from the reservoir occurs due to natural mechanisms. In the secondary stage, there is always depletion of the reservoir pressure which is not sufficient to drive the production from the formations naturally, secondary recovery methods are employed to maintain the reservoir pressure and hence maintain production [7]. Water flooding is the main secondary recovery driving mechanism for maintaining reservoir pressure because of its availability and the low cost of the injection fluid (water). Over the decades, research has shown that 20-40% of crude oil in reservoirs is obtained by the primary and secondary recovery methods [7]. This is because primary and secondary oil recovery processes are governed by the reservoir pressure, pressure maintenance mechanisms (water flooding) and usually, after these recovery processes, a considerable amount of oil is trapped in the reservoir pore spaces due to microscopic and macroscopic factors. To achieve maximum oil recovery from these reservoirs, these forces must be overcome, and this can be achieved with the use of external forces. The process of doing this is referred to as tertiary oil recovery or Enhanced oil recovery (EOR) methods [7-8].

The main EOR methods are thermal recovery (injection of steam or hot air into heavy reservoirs to decrease the oil viscosity and promote oil flow towards the wells), gas flooding (injection of CO₂), chemical flooding (use of alkaline, surfactants and polymers) and microbial injection. The method of EOR applied for a specific reservoir is based on three key factors namely; the reservoir depth, the oil viscosity and the reservoir permeability [9-12].

Chemical Enhanced oil recovery (CEOR) methods involve the injection of a displacing fluid into oil reservoirs to reduce the reservoir surface tension and increase the mobility of crude oil trapped in it. The displacing fluid is typically a mixture of water and a water-soluble polymer alone or in combination with a surfactant and/or an inorganic base. A lot of research has been done on CEOR techniques and have been extensively described in different books and articles [10-11].

The use of polymers for EOR is called polymer flooding. The mechanism of polymer flooding bases on the fact that the sweep efficiency of crude oil in a reservoir can be improved by reducing the mobility difference between the oil and the displacing fluid(water). Polymer flooding helps to reduce the mobility difference by increasing the viscosity of the displacing

fluid. The viscosity of pure water is usually less than that of oil and hence in polymer flooding techniques, synthetic polymers such as polyacrylamide and partially hydrolyzed polyacrylamide and biopolymers such as xanthan gum have been used to act as an effective viscosifier for the displacing fluid [9-13]. In addition to being used as flooding agents, polymers can also be used to selectively plug/seal thief zones (other reservoirs connected to a target reservoir which steal some of the reservoirs pressure), whose existence reduces the sweeping efficiency of flooding solutions by allowing the preferential flow of injection solution [13-14].

Apart from synthetic polymers, biologically derived polymers have also been proved to play a significant role in improving the sweep efficiency of oil [15-16]. From research, the viscosity of polymer solutions is related to the molecular weight, polymer concentration, water salinity, temperature [17-19]. Also, an important factor that determines the usage of a polymer for EOR is its thermal stability at high temperatures. Thus, a biopolymer with good thermal stability and other desirable characteristics has to be identified and tested to evaluate its effective usage as a viscosifier or pore plugging agent. This research work involves the use of waste potato peels as a novel bio-polymer for enhanced oil recovery and the modelling of the polymer viscosity using artificial neural network (ANN).

2. MATERIALS AND METHODS

2.1. Potato starch biopolymer extraction

1.5grams of sweet potato peels were obtained as waste from the production of potato chips at the Covenant University Cafeteria 2. These peels were used in the extraction of the potato starch required as biopolymer for enhanced oil recovery. Potato starch biopolymer was extracted from the potato peels through the steps shown in Fig. 1. The potato peels were thoroughly washed with clean water to remove any dirt and debris present. The peels were then grated to increase the surface area required for extraction. The grated peels were then soaked in lukewarm water for 10 minutes, to soften the peels.

The peels were blended, using an electronic blender (MJ-176NR Woodland), for 30 minutes to obtain a slurry. The slurry was then sieved using a 100 μm muslin cloth to remove shaft. The brown filtrate obtained was collected while the shaft was further soaked and then subjected to second stage of blending (to recover more filtrate) before being discarded. The filtrate was allowed to settle for 12 hours to obtain a clear liquid and acaked white starch sediment. The sediment was then allowed to dry under the sun for 4 hours after which it was further dried in the oven at 50°C for 20 minutes. The dried starch was then turned to a fine powdered starch biopolymer using blender.

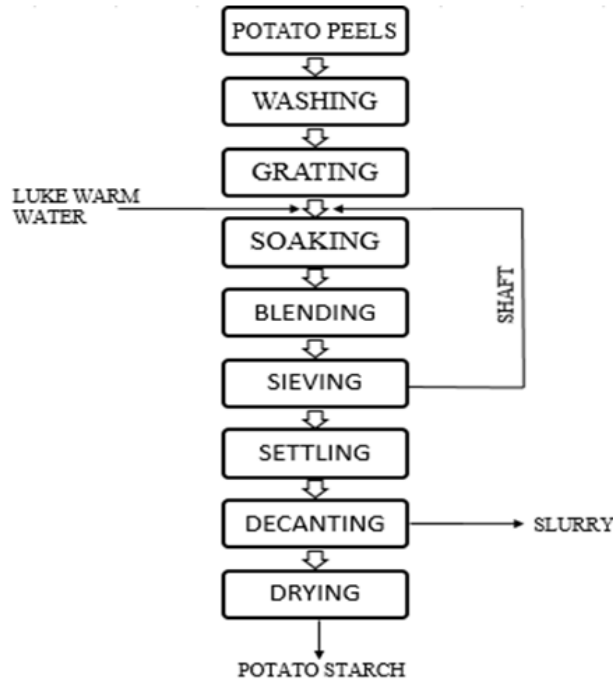


Figure 1 Potato starch biopolymer production process

2.2. Assessment of EOR applicability of produced biopolymer

The assessment of the EOR application potential of the biopolymer produced was done by carrying out the following studies.

2.2.1. Rheological studies

The viscosity of the varied concentrations of the biopolymer in water was measured at 25 °C, using rheometer (DMA 850). The dial readings from the rheometer were obtained at 6rpm, 30rpm, 60rpm, 100rpm, 200rpm, 300rpm and 600rpm respectively. The shear strain of these readings were determined.

2.2.2: Molecular weight determination

A Ubbelohde viscometer was used to determine the viscosity of the biopolymer, at 25 °C, using water as the solvent. The determination of the polymer solution flow time was carried out by considering different volumes of the polymer solution at varied concentrations. Huggins' and Kraemer plots were generated for the polymer, the plots were used to infer the intrinsic viscosity of the biopolymer which was in turn used in calculating the molecular weight of the polymer using Mark-Houwink-Sakurada's equation.

2.2.3: Thermal stability studies

To test the thermal stability of the produced biopolymer, a polymer solution with a concentration of 20 g/l was prepared and heated up to 120°C. Viscosity measurement was immediately conducted at different temperature as the solution cooled from 100°C to 25°C. The viscosity changes of the polymer with temperature was then plotted.

2.2.4: Pore plugging studies

The pore plugging studies was carried out to evaluate the potential of the polymer to selectively plug the reservoir pores. In this study, sand columns were used to evaluate the pore plugging ability of the starch polymer. The sand was mixed with water and the biopolymer in different proportions to obtained slurry (sand: polymer of 100:0, 100:1, 80:1, 60:1, 40:1, and 20:1). The sand to polymer ratio of 100:0 served as control for the process. The slurry obtained was fed into a 50ml syringe and then allowed to dry in the oven at 50°C for 24 hours. After drying, a layer of sand was placed over the columns that had caked in the syringe and 10ml of water was poured over the columns. Pore-plugging ability of the polymer was evaluated by observing the percolation of the water through the sand columns by wetting action over time. As reported by [5], the plugging efficiency of the polymer was expressed in terms of dripping rate of water through the column (Fig. 2).

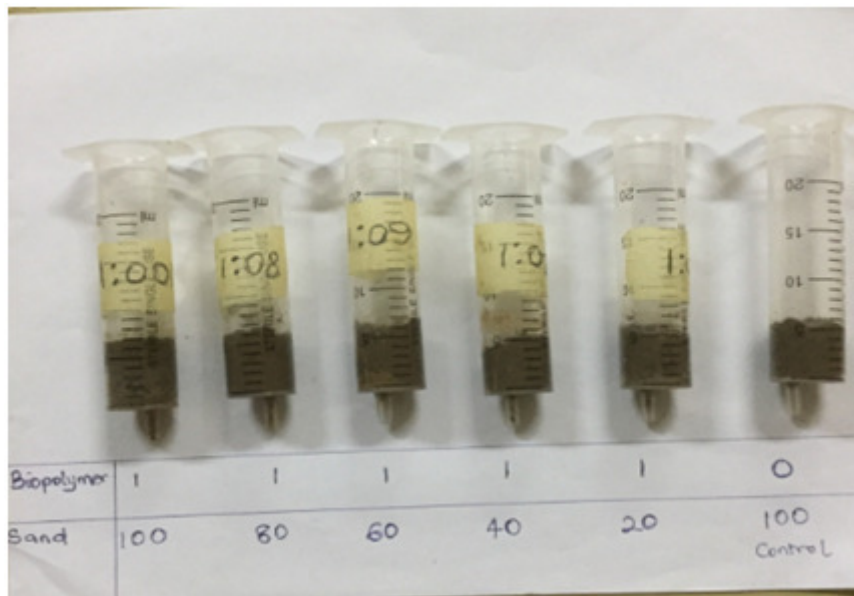


Figure 2: Setup for pore plugging test

2.3: Modelling of polymer viscosity for enhanced oil recovery (EOR) using Artificial neural network (ANN)

A central composite design (CCD) was employed for the experimental design, using Minitab 17.1.0, software and this resulted into 20 different experimental runs of the combinations of three input parameters (polymer concentration, salt concentration and shear rate) with viscosity as response. MATLAB 9.2.0 software was utilised to carry out the optimization. An Artificial Neural Network (ANN) model was developed and trained using the CCD data with feed-forward back propagation (BP) algorithm.

To develop ANN model, the input layer of three neurons considered are shear rate, polymer concentration and salt (NaCl) concentration. For training, validating and testing of the ANN model, the measured viscosity data for each run from the CCD data shown in Table 1. This data was randomly divided into three parts; 70% for training, 15% for validation and 15% for testing. For the training, the Bayesian Regularization based MATLAB (trainbr) function and Levenberg-Marquardt algorithm were applied to produce a model that best fit the data (this is explained further in the appendix). After various iterations of trial and error, the ANN model for the polymer viscosity was developed.

Table 1 Polymer viscosity for 20 experimental runs from CCD.

S/N	Polymer concentration (g/l)	salt concentration (g/l)	shear rate (rpm)	Viscosity (cP)
1	5	0.1	30	15
2	20	0.1	30	20
3	5	1	30	14.5
4	20	1	30	19.5
5	5	0.1	200	3.75
6	20	0.1	200	9
7	5	1	200	4.5
8	20	1	200	9
9	15	0.55	100	7.5
10	20	0.55	100	13.5
11	10	0.2	100	9
12	10	1	100	6
13	10	0.55	30	15
14	10	0.55	200	4.5
15	10	0.55	100	7.5
16	10	0.55	100	6
17	10	0.55	100	6
18	10	0.55	100	9
19	10	0.55	100	7.5
20	10	0.55	100	6

3. DISCUSSION OF RESULTS

3.1. Molecular weight determination

From the Huggins' and Kraemer plot developed using the polymer flow time obtained from the Ubbelohde viscometer (U-tube viscometer), the intrinsic viscosity ($[\eta]$) of the potato starch biopolymer is 7.36 dl/g (Fig.3). Using the Mark-Houwink equation, this corresponds to a molecular weight of 1.36×10^6 g/mol. The value of the molecular weight of the potato starch polymer obtained in this research was close to that of the two commonly used polymers (HPAM and Xanthan) and serve as a suitable polymer for polymer flooding [20]. This is because, the molecular weight of polymers for EOR is directly proportional to the viscosity of a polymer solution developed from dissolving the polymer in water. The higher the molecular weight, the higher the viscosity that can be attained using the polymer.

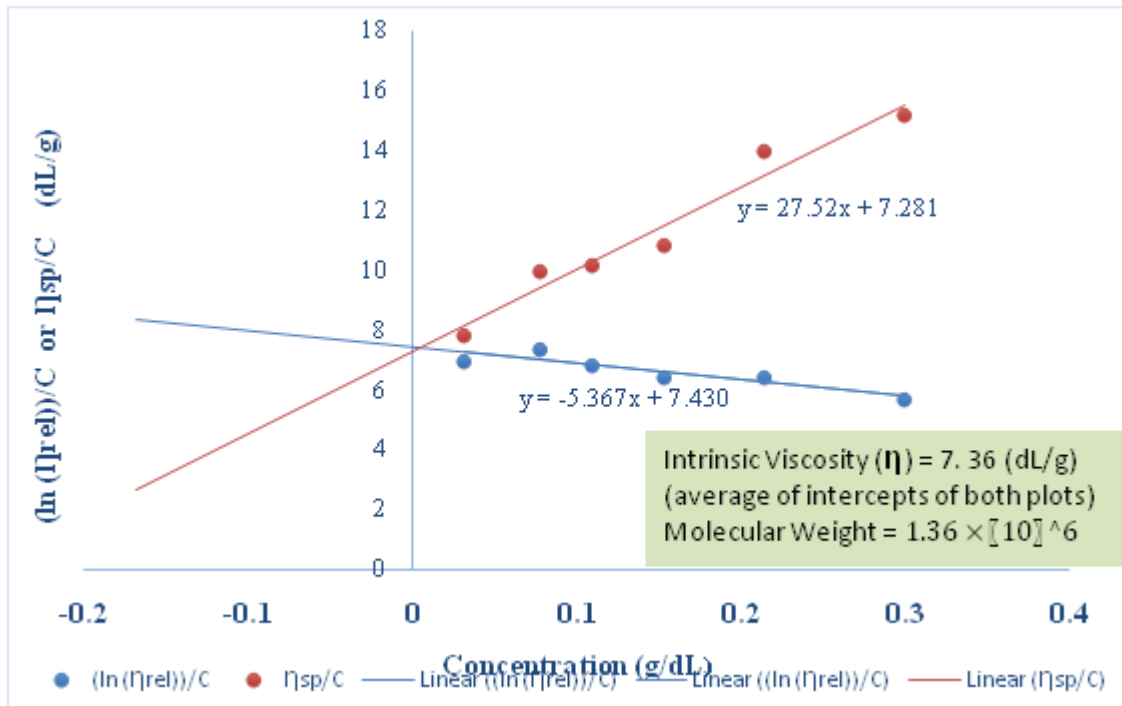


Figure 3 Huggins' and Kraemer plots for inferring intrinsic viscosity of the biopolymer

3.2. Pore plugging studies

The ability of the polymer solution to plug the reservoir pores during EOR applications was demonstrated by testing the ability of the polymer to prevent water from passing free through sand-columns. Each of the sand columns showed that the product was able to plug the sand pores within the column. The percolation of water through a column filled with just sand was used as control and the rate of water dripping through the column was so rapid after 1 min of adding the water over the sand layer.

On the other hand, the remaining sand columns that contained the polymer were completely impervious to water for more than 24hrs. After 32hrs, the water could diffuse through the sand column with 20:1 w/w of sand to polymer and took 128mins for all the water to flow through the column. Fig.4 shows the flow rate of water through all the columns and it can be observed that the dripping rate as the sand to polymer ratio was increased from 20:1 to 100:1, the water dripping rate increased from 0.0469 mL/hr to 2.65 ml/hr . This shows that the polymer acted as a gel and was able to completely block the sand pores.

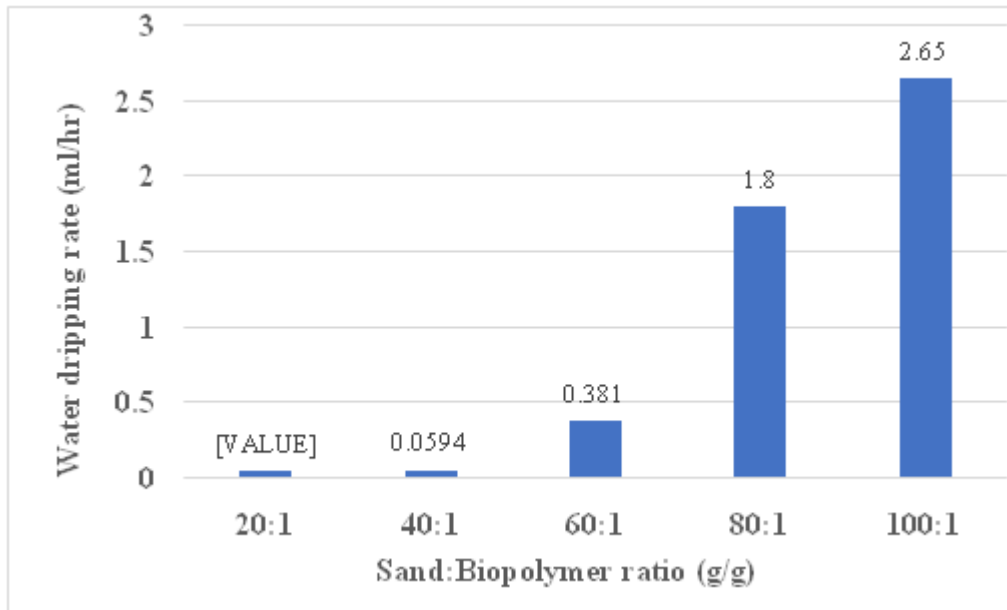


Figure 4 Dripping rate of water through sand columns.

3.3. Rheological studies

The results of the rheological characterisation carried out by measuring the viscosity of polymer solutions with different polymer concentrations showed that the polymer exhibits non-Newtonian behaviour for all concentrations tests. The effect of the shear stress imposed on the polymer at different shear rates is shown in Fig.5. From the viscosity measurement, the viscosity of the polymer at a particular shear rate increases as the polymer concentration increases. The plots of viscosity against shear rate for the polymer solution at all concentrations show that the apparent viscosity of the polymer solution begins to thin out at shear rates greater than $5s^{-1}$ (300 rpm). This shows that at shear rates higher than this, the polymer solutions tend to act like a Newtonian fluid which is not so favourable. In addition, the effect of salt concentration on the polymer viscosity was examined and it shows that the polymer viscosity was relatively constant irrespective of increase in salt concentrations.

The Non-Newtonian behaviour of the polymer shows that the polymer viscosity would increase as it flows injection well head to the target reservoir. This is because the polymer is more susceptible to mechanical shear at the well head than at the reservoir. Hence, this is a favourable property for EOR.

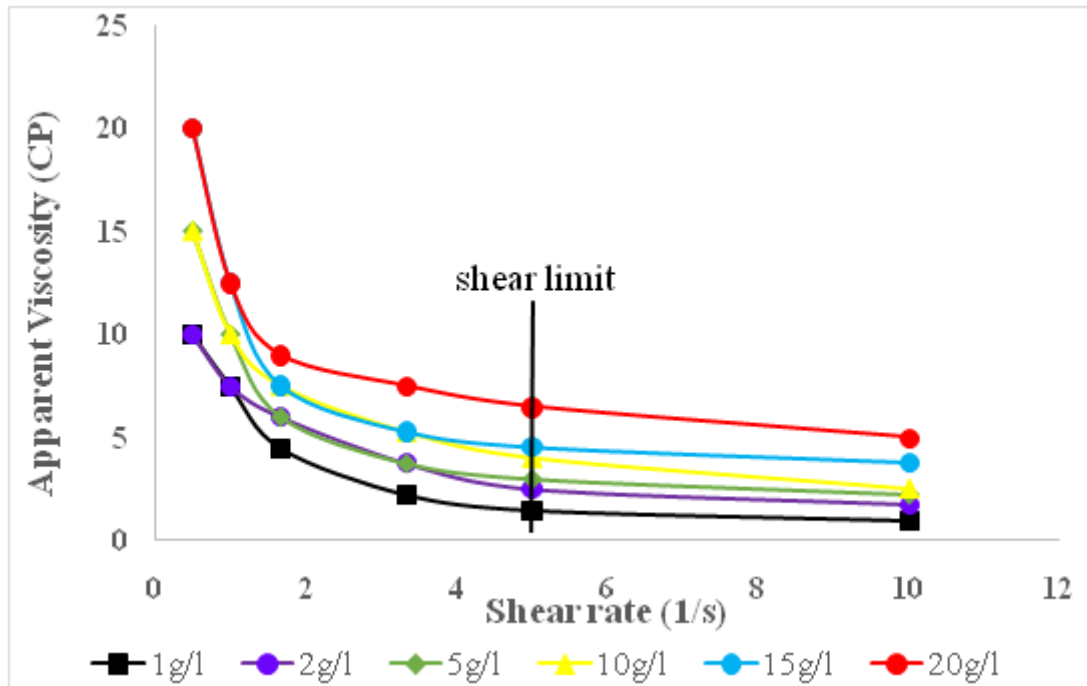


Figure 5 Apparent viscosity versus shear rate of biopolymer at concentrations of 1 g/L, 2 g/L and 5 g/L

3.4. Thermal stability studies

The viscosity of the potato starch biopolymer was examined at various temperatures. These values were plotted against the viscosity as shown in Fig.6. The results show that the viscosity declined with increase in temperature and at 100°C the biopolymer had lost about 40% of its initial viscosity at 30°C. HPAM and Xanthan at 90°C lose 32 and 50 % of their original viscosity, respectively [20]. In comparison to these values, the potato starch biopolymer is relatively as thermally stable as HPAM and more thermally stable than Xanthan gum. Hence, the polymer is about 60% relatively stable at temperatures up to 100°C.

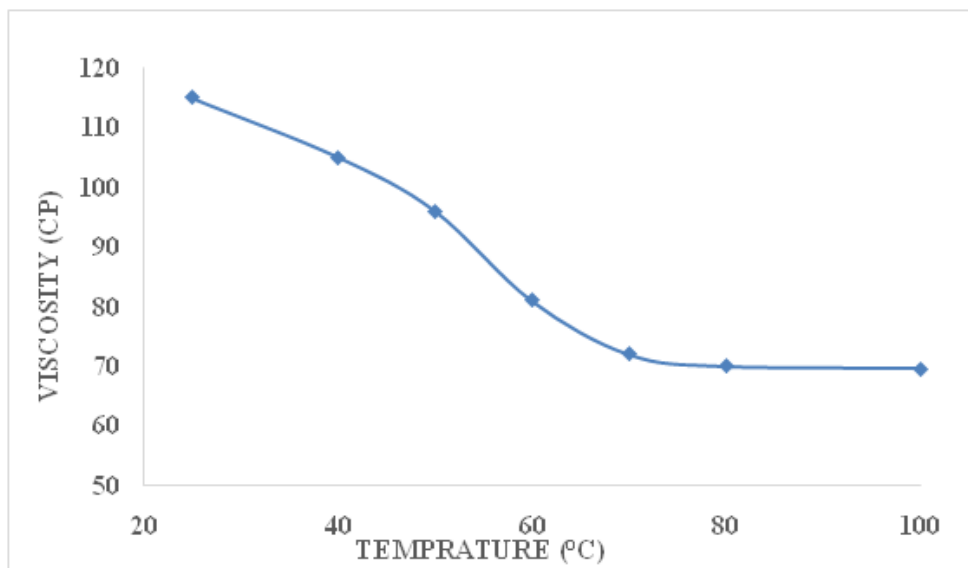


Figure 6 Viscosity of polymer solution (20g/L) versus temperature

3.5. ANN modelling

For the model implementation using MATLAB, the CCD data sets were trained using both the Bayesian Regularization back propagation algorithm and Levenberg-Marquardt back propagation algorithm, and training iterations were tried for each run. The Levenberg-Marquardt algorithm failed to converge with a suitable generalisation for the data based on the mean Square Error (MSE) and the overall correlation coefficient (R) values obtained. The iterations for the Bayesian Regularization showed good generalisation and were terminated when the generalization stopped improving, as indicated by the Mean Square Error (MSE) and the overall correlation coefficient (R) of the validation samples as shown in Figure 8(a) and (b). The Mean Squared Error (MSE) is the average squared difference between output of the model and target (i.e. the error between the viscosity values obtained experimentally and that predicted by the model). The lower (the closer the value is to zero) this error is, the better the model developed. An MSE value of zero indicates no error at all. The regression (R) analysis is performed to measure the correlation between outputs and targets. An R value of 1 means a close relationship and 0 means a random relationship.

Developing the ANN model using the Bayesian Regularization in the MATLAB neural network environment involves carrying out various iterations to train the model using 70% of the CCD data earlier generated (this corresponds to 14 samples). Simultaneously, the model is validated using 15% of the CCD data (3 samples). After the simultaneous process of training and validation, MSE and regression analysis was carried out on the model for training and validation. The regression plots obtained are shown in Fig.7. The MSE and regression results for the training and validation are shown in Fig 8.

After, the model developed was validated in the neural network environment using the remaining 15% of the CCD data (3 samples). MSE and regression analysis were also carried out on the validation data. From Fig 8(a), the MSE value (0.0178481) for the training and validation of the model is very low. This shows that the error is very minimal, and the model is a good generalisation of the viscosity of the potato starch biopolymer based on changes in polymer concentration, salt concentration and shear rate. Also, from Fig.8(b) it is seen that the regression values for training, testing and validation of the model are very close to 1. This means that the model developed gives a very close relationship between the output and the target with very minimal error.

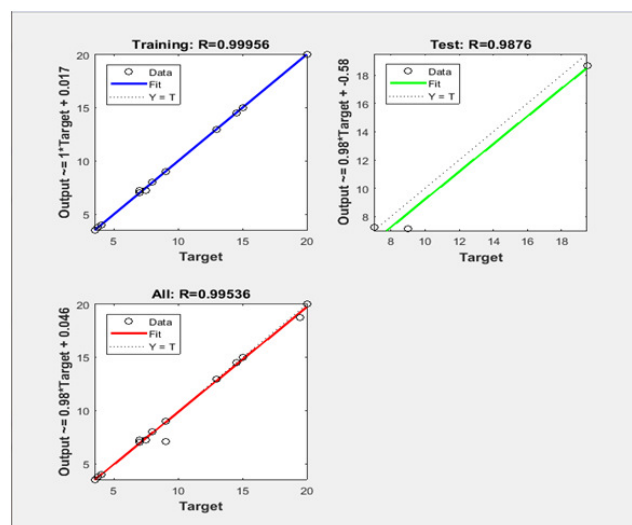


Figure 7 Regression plots obtained for training and validation of the ANN model.

Results			
	Samples	MSE	R
Training:	14	1.78481e-2	9.99563e-1
Validation:	3	0.00000e-0	0.00000e-0
Testing:	3	1.41911e-0	9.87600e-1

(a)

MSE	2.28038e-1
R	9.95357e-1

(b)

Figure 8 MSE and R values for (a) model training & testing and (b) model validation

The data of the viscosity predicted by the ANN model was then generated in MATLAB and this was plotted against the corresponding the experimental values as shown in Fig. 9.

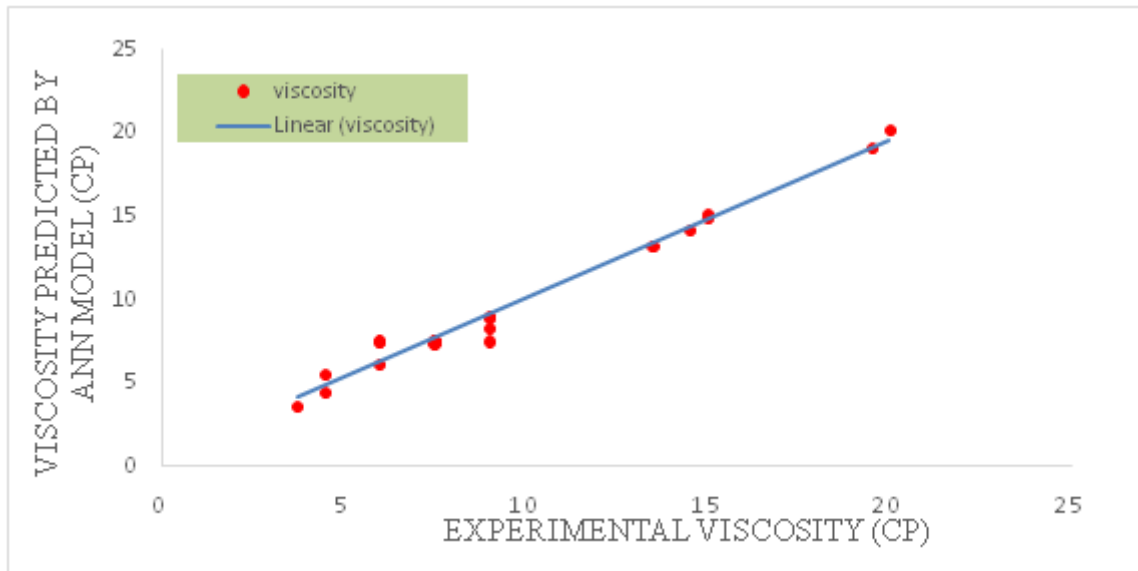


Figure 9 The experimental viscosity data against the ANN predicted data

4. CONCLUSION

In this study, a novel bio-polymer from potato peels for polymer flooding to serve as a viable alternative to chemically synthesized polymers was produced. This is due to the fact that the rheology, thermal stability and pore-plugging ability of the produced polymer demonstrate that the polymer can be successfully used for EOR applications. Also, at the end of this study it has been realized that the feedforward backpropagation neural network model with supervised learning, can be used to successfully model the viscosity parameters of the polymer.

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