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Flow Improvement and Viscosity Reduction for Crude Oil Pipelines Transportation Using Dilution and Electrical Field

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H I G H L I G H T S

- Combination of electric field and Dilution can improve the flow of heavy crude oil.
- Invented capacitor has been put inside the oil pipe to apply electric field.
- Optimize the conditions of applying the electric field and acetone addition.
- Significant improvement in pumping power has been revealed at optimum conditions.

A R T I C L E   I N F O

A B S T R A C T

One of the great challenges in pipeline transportation of heavy crude oil is the effect of viscosity on flow rate. By using viscosity reduction techniques, crude oil flow ability can be enhanced. However, the dual effect of dilution and electric fields on crude oil flow ability is still not well addressed. The main goal of this study is to reduce viscosity and improve the flow rate of heavy crude oil through pipelines using dual techniques of electrical field and dilution. The optimization technique was used to investigate the interaction effects of experimental variables on the objective function. As compared to crude oil treated solely by dilution or electrical field, the dual treatment could result in more substantial reductions in viscosity. In this experiment, at first, the dilution's impact is studied. Acetone was used as a diluent in different concentrations. The great viscosity reduction is about 21.98% when adding 20 wt. % of acetone. Secondly, when the effect of the electric field has been studied, a reduction in viscosity of about 35.6% was observed when 36.67(v/cm) is applied. Lastly, the effect of combined treatment (dilution and electric field) has been investigated according to factorial design. The optimum viscosity reduction is about 61.856% at 11 wt. % acetone and 36.67 (v/cm) of the electric field.

1. Introduction

Crude oil is one of the most important sources of energy that has faced an increase in demand in the world since the last decade; its production has increased to 84 million barrels per day in the past 20 years. It is considered as the main provenience of the economy in many countries, especially Iraq which has traditionally provided about 95% of foreign exchange earnings [1].In many parts of the world, heavy crude oil is transported from the place of production to refineries or ports via pipelines. Pipelines can be considered one of the safest tools for transporting crude oil over long distances. Therefore, these tools are used to export crude oil, but the movement of crude oil in pipelines is low due to the high viscosity of heavy crude oil due to the presence of some unwanted components such as asphalt, heavy metals, and sulfur which makes it more difficult to produce and transport as well as reprocessing. Transporting heavy crude oil through pipelines represents a great challenge due to its inability to flow freely [2, 3]. Without prior viscosity reduction of heavy crude oil, transportation through pipelines is very difficult because of the tremendous energy required to overcome the high-pressure drop in the pipeline due to the high viscosity [4]. Generally, there are different methods used to enhance the transportation of viscous petroleum through pipelines that include heating, dilution, and electric field [5].

Dilution can be specified as a traditional approach utilized for reducing the crude oil viscosity and the most common as it has had an effective contribution in the field of reducing viscosity from the 1930s to the present day. The main idea of the dilution was to mix the heavy oils with diluents that have a very low viscosity. Dilution with the solvent represents an efficient technique in viscosity reduction. The reduction in viscosity has a decisive advantage that is avoiding increases in the pressure drop and reducing a pumping cost, moreover helping the steps of dehydration and desalting in a downstream treatment process [6, 7]. Recently, many studies focus on a dilution method using a different solvent to achieve a certain viscosity [8]. Mortazavi et al. [9] showed the mixture of (toluene + butanone) addition with a ratio (50/50 vol. %) under different temperatures (-15 to 60 °C) is the best solvent for decreasing the thixotropic effect and viscosity reduction in comparison with toluene and n-

heptane alone. Azeez et al. [10] used toluene and dimethyl ketone as diluents (50/50 vol. %) in different dilution ratios for reducing the Iraqi crude oil's viscosity. The viscosity was examined when the solvents were present at various temperatures. In addition, the results show that the mixture consisting of toluene and dimethyl ketone (50/50% vol.) has an effective effect on reducing viscosity. However, the higher degree of viscosity reduction indicated approximately 87.17% at 15 wt. % of the mixture (50/50 vol. %) toluene as well as dimethyl ketone at 318.15 K and (42 s^{-1}) shear rate. The relevant results are due to toluene's aromatic characteristic allowing interferes in asphalting aggregation. Majored et al. [11] studied the processing of heavy Iraqi crude oil obtained from the East Baghdad field (22.2 API) and used many additives to reduce viscosity. Various additives' types have been utilized for reducing the viscosity; also, experiments are conducted on the heavy oil sample with the use of many solvents (n-Propanol, Ethanol, and methyl ethyl ketone (MEK)). From every utilized type, MEK has been the major viscosity reducer regarding heavy crude oils, while the maximal reduction of viscosity reaches 3.78cSt at a temperature of 75°C and 26 API at a temperature of 25°C, however, the other solvents concerning n-propanol 5.85cSt at a temperature of 75°C and 24.61API at 25oCwhile for ethanol 5.96cSt at 75oC and 27API at 27oC. Martínez-Narro, et al. [12] used polypropylene and polystyrene as a diluent to reduce the viscosity of Mexican crude oil, where they used 5%, 10%, and 15% of the diluent. The results showed that at room temperature, by using 15% of the diluent, viscosity reduction was obtained from (96%- 97%). It was found that the maximum transfer of pipelines was achieved at temperatures (45° C -56° C). Recently, a lot of research indicated that the electric field has the ability for reducing the heavy crude oil's viscosity. The electric field has various benefits in the crude oil pipelines, particularly in the viscosity reduction regarding crude oil lasting for a few hours. In the case when the electric field has been utilized along the flow direction in a small pipeline's section, the field is polarizing and aggregating the particles which are suspended in the base liquid in short-chains along the direction of the flow. These aggregations are breaking the rotational symmetry as well as making the fluid viscosity anisotropic. There is a considerable reduction in the viscosity along the direction of the flow; therefore, there is an enhancement in the flow along the pipeline. Also, the technology is consuming a lot of energy; its development was extremely rapid, more effective compared to other technologies. The electric field is efficient in the reduction of the viscosity that is related to paraffin base crude oil and asphalt base crude oil [13, 14]. Ibrahim et al. [15] utilized the approach of the electrical field as well as dual treatment (electric field+ Nanomaterial) for decreasing the Iraqi heavy crude oil viscosity; the researchers applied the electrical field on crude oil pipe. Furthermore, they utilized various values of electrode distance, applied voltage, Nano-silica, and treatment time concentration ranging between (2-10) cm, (140-220) V, (0-700) mg L-1, and (0-60) s. With regard to 31.2oAPI crude oil experiment, application of voltage (188V) at 10 Celsius for 32 s, with 6.11 cm distance between the electrode, and with no addition of Nano-silica, results in the viscosity to be reduced from 32.5cSt to 20.479cSt, which lead to an increment in the flow rate by 45.6%. In addition, applying a voltage of (188V) at 10 Celsius for 32s, with 6.11 cm distance between the electrode, also with Nano-silica addition of 100 mg L-1, results in the viscosity to be reduced from 32.5 cSt to 12.8 cSt, by 60.6%; thus, the flow rate will be increased by 77.8%. Xie et al. [16] improved the flow ability of Heavy crude oil by reducing its viscosity and weakening waxy gels using dual treatment electric field and Ethylene-Vinyl Acetate copolymer (EVA). A viscosity reduction of as high as 59.1% can be achieved at a shear rate of 10 s−1 and 25 °C with the combined treatment. This viscosity reduction is 22.0% and 18.2% higher than that achieved with the electrical and EVA treatments alone. However, the overall improvement in the flow ability achieved by the combined treatment is lower than the sum of the improvements achieved by the electric field and EVA. In this work, the major objective is reducing the viscosity and enhancing the flow of heavy crude oil via pipelines using combined treatment as an electrical field and dilution with acetone. The investigation of experimental variables' interaction effects on the objective function using optimization technique has also been achieved.

2. Fluid flow governing equations

Fluid flow governing equations are utilized for calculating the characteristics of fluid flow [17-19]. Also, the dynamic viscosity (μ) might be acquired from kinematic viscosity (v) measurements based on (Eq. 1), with 0.853 gm/cm3 as crude oil density. In addition, the Reynolds number indicates the type of flow and shows the impact of viscosity resistance at 13.78 cm/s fluid velocities. It might be estimated with the use of (Eq.3). Furthermore, the shear stress can be specified as the multiplication regarding shear rate value with the dynamic viscosity, as can be seen in (Eq. 4). While the value that is related to shear rate ẏ was constant at 25.63 Sec-1 acquired as (8u/d), (d) refers to the diameter of the pipeline equal to (4.3cm). The pressure drop represents the dissipation of the energy due to friction. It might be evaluated based on (Eq.5), which represents the pipe's length (150cm). The power consumption to pump the specific amount of the crude oil at 13.78 cm/s constant velocities was evaluated via (Eq. 6) before and following each treatment, in which γ pumping efficiency of (85%). Q refer to volumetric flow rate obtained experimentally from graduated cylinder its equal to 200 (cm3/sec).

$$\mu = \rho v \tag{1}$$

$$Re = \frac{\rho u d}{\mu} \tag{2}$$

Substitute equation (1) into (2) to give:

$$Re = \frac{u d}{v} \tag{3}$$

$$R_w =$$ (4)

$$\Delta P = \frac{4 R_w\, l}{d}$$ (5)

3. Optimization Technique

3.1 Design of Experiments

There were various approaches for an experimental planning application, for instance, factorial design. Also, the total number of experiments in such design has been equal to (2 n +2 n +1), in which n represents the number of variables, plus more treatments for considering the experimental error and lack fit [20].

3.2 Polynomial Representation of the Objective Function:

In the polynomial, the number of terms might be evaluated as follows:

$$number\ of\ terms = \frac{(n+1)(n+2)}{2}$$ (6)

The operating variables such as acetone concentration (x1), voltage (x2), have been correlated in nonlinear 2nd order in terms of Shear stress, Reynolds number, pressure drop, and Power consumption for pumping that represent via the objective function (y) for being minimized as can be seen in eq. (8):

$$y = a_0 + a_1\, x_1 + a_2 x_2 + a_3 x_1 x_2 + a_4 x_1^2 + a_5 x_2^2$$ (7)

The corresponding coefficients regarding the polynomial above (a0, a1…a5) are referred to as "Regression Coefficients"[20].

3.3 Optimum Conditions

The optimum conditions might be acquired via developing a group of (14) constraints; which can be specified as follows:

$$a_{11}x_1 + a_{12}x_2 + \cdots a_{1n}x_n (\leq, \geq, =) b1$$ (8)

$$a_{21}x_1 + a_{22}x_2 + \cdots a_{2n}x_n (\leq, \geq, =) b2$$ (9)

$$a_{m1}x_1 + a_{m2}x_2 + \cdots a_{mn}x_n (\leq, \geq, =) bm$$ (10)

$x_i \geq 0 (i = 1,2\ldots n)$,,   m=number of constraints, b= constraints results.

The Regression Coefficients have been assessed with the use of STATISTICA V (8.0), and then the variables of operation enhanced utilizing WinQSB V (2.0) for estimating the optimum value related to operating conditions to reduce the viscosity of crude oil and pressure drop.

4. Experimental Part

4.1 Materials

The crude oil sample used in this study was supplied from Al-Dora refinery in Baghdad city. The Specifications are listed in table 1.

Dilution with solvent is of high importance recently due to its simple application. Also, the reduction of viscosity via combining a light solvent, for example, acetone, with heavy oil has some benefits such as: maintaining the hydrocarbon's original characteristics; it could be utilized at various locations regardless of the climate conditions. The acetone (purity = 99.9%) was purchased from a local market supplied by Greenfield global (PHARMCO COMPANY). The reason for choosing acetone as a diluent with the electric field is since it is considered one of the solvents that have a high dielectric constant ($\boldsymbol{\varepsilon}$ =20.7), which leads to the ease of polarization and rearrangement of particles when used with the electric field.

4.2 Experimental system

The experimental system comprised of Oil pump, Perspex oil pipe with outer diameter of 45 mm, the thickness of 2 mm, and length of 150 cm, control circuit (timer, bridge rectifier, voltage regulator, relay, and digital voltmeter), and solenoid valve. The schematic diagram of the experimental system is shown in Figure 1.

Table 1:   Crude oil Specifications

Test	Specification
API Gravity at 15°C	30.123°API
Sp.gr at 15 ºC	0.8724
Viscosity at 21 ºC	31.7 (cSt)
Density at 15 ºC	0.886l (gm/cm^3)

The invented parallel circular plate capacitor has been put alongside the oil pipe; it comprises of two electrodes in the form of a perforated circular disk made of 2 mm thick stainless steel with a 38.4 % open area. There are 20 holes, each with a diameter of 6 mm. The capacitor operating mechanism proposes that when crude oil flows over a capacitor electric field, paraffin and asphalting particles are organized in short chains, allowing for sliding. Figure 2 Shows the design of the capacitor electrode.

4.3 Experimental procedure

Firstly, Acetone with a viscosity of 0.298 (cSt) and five concentrations (0, 5, 10,15and 20 Wt. %) mixed with crude oil via magnetic stirrer for 20 minutes. Then viscosity measurement with a viscometer type Ostwald with 0.7 mm capillary diameter to investigate the effect of acetone only (dilution) on the crude oil viscosity. Secondly, to study the electric field's impact upon crude oil's viscosity, the experimental system was used; only crude oil was placed in the experimental system tank different voltages were applied (140,160.180, 200, and 220V) for 30 sec. Finally, according to factorial design, fourteen experiments were conducted for testing the impact of two experimental variables (voltage (x1) from 140v to 220v) and (acetone concentration(x2) from 0 Wt. % to 20Wt. %) at treatment time of 30 sec and constant distance between capacitors electrode 6 cm as design parameters. Samples of crude oil after treatment with an electrical field and diluted with acetone were collected in the beaker to measure samples viscosity experimentally and the volumetric flow rate measurement using a graduated cylinder.
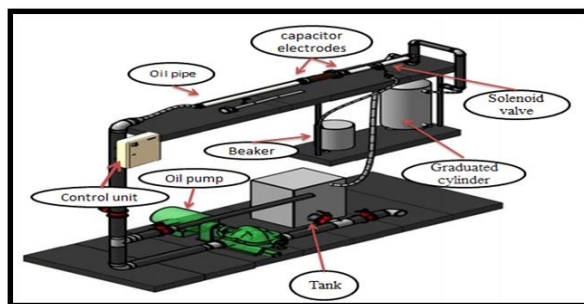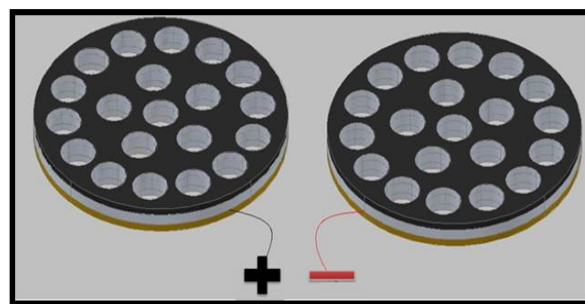

Figure 1: Schematic diagram of the experimental system

Figure 2: Design of capacitor electrodes

5. Results and discussions

5.1 Experimental Results

The effect of different concentrations of diluent on heavy oil kinematic viscosity is established at atmospheric pressure, and 21ºC, the value of shear rate was 25.63 Sec^{-1}. The obtained results are shown in table (2). Also, the effect of different concentrations of acetone on the kinematic viscosity of crude oil is presented in Figure 3. The graph shows that the viscosity was decreased exponentially with increases in the concentration of acetone from 0 to 20wt. %. The lesser value of viscosity was about 24.73cSt at 20 wt. % of the acetone. So, the maximum viscosity reduction (VR) is about 21.9 % when adding 20 Wt. % of acetone. These results are since acetone is a good solvent for glues, resins, petroleum fats, and aromatic characteristic that allows interferes in asphalting aggregation; a similar trend was noted by Azeez et al. [10], and Majeed et al. [11]. In viscosity reduction, the applied electric field is considered to be of high importance. As the crude oil passes the electric field, then the suspended asphaltenes, as well as paraffin's particles, will be polarized and aggregated into short chains, resulting in low viscosity [13]. The obtained results are presented in table (3); as was noted in figure 4 the viscosity continued to decrease with increasing the value of the electric field attributed to the rearrangements regarding microparticles in short straight chains. Furthermore, the results are showing that the minimum value of viscosity as 20.41cSt was obtained when an electric field of 36.67(V/cm) was applied. So, the maximum (VR) is about 35.6%. A similar trend was noted by Amna M. Mustafa [21].

In this experiment, the reduction of viscosity occurs due to two major factors: electric field intensity and dilution effect. The Effect of dual treatment (dilution and Electric Field) on viscosity cause an effect on fluid flow characteristics can show in Table 4.

Table 2: Effect of dilution on fluid flow characteristics (without electric field application)

EXp. No	Acetone Concentration (Wt. %)	Kinematic Viscosity (cSt)	Dynamic viscosity (cP)	Reynolds number (-)	Shear Stress (Pa)	Pressure Drop (Pa)	Power consumption (Watt)	Viscosity reduction (VR %)
1	0	31.7	27.04	187	0.693	96.69	22.750	0
2	5	29.83	25.44	205	0.652	90.97	21.404	5.8
3	10	25.42	21.68	233	0.555	77.42	18.216	19.81
4	15	25.22	21.51	235	0.551	76.88	18.089	20.44
5	20	24.73	21.09	240	0.540	75.33	17.724	21.98

Table 3: Effect of Electric Field intensity on a fluid flow characteristic (Without dilution)

EXp. No	Voltage (v)	Electric Field Intensity (v/cm)	Kinematic Viscosity (cSt)	Dynamic viscosity (cP)	Reynolds number (-)	Shear Stress (Pa)	Pressure Drop (Pa)	Power consumption (Watt)	Viscosity reduction (VR %)
1	140	23.34	28.99	24.72	204	0.633	88.303	20.777	8.54
2	160	26.66	28.58	24.37	207	0.624	87.048	20.481	9.84
3	180	30	25.75	21.96	230	0.562	78.399	18.446	18.77
4	200	33.34	21.74	18.54	272	0.475	66.262	15.591	31.42
5	220	36.67	20.41	17.41	290	0.446	62.217	14.639	35.61
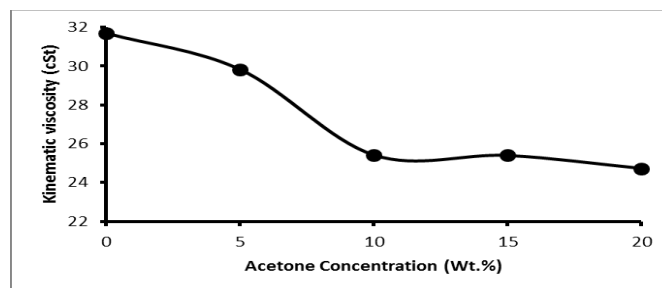
Figure 3: Viscosity of crude oil at different dilution ratios

5.2 Optimization results

The objective function is represented by a second-order polynomial as in Eq. 7 is applied for different characteristics as (viscosity, Reynolds number, shear stress, pressure drop, and power consumption), the polynomial coefficients are obtained using Statistical software version 8. The coefficients are listed in Table 5.

Wins software version 1.0 is utilized to provide the optimum conditions, table 6 shows the results. It might be specified that at optimal conditions, the value that us related to the viscosity of the crude oil was lowest in the range of operating input variables. The software's working concept is to seek the lowest value regarding the objective function (i.e., the viscosity), whereas it was subjected to the minimization function. The software is working with 14 constraints to be solved with the use of the nonlinear programming (NLP) approach for finding optimum variables in the experimental range.

5.3 The impact of experimental variables on Viscosity, Reynolds Number, Pressure Drop, Shear Stress and Power Consumption.

5.3.1 Effect of electric field intensity:

The value of the electric field intensity showed a noticeable effect on viscosity reduction. However, as the electrical field intensity increases, the viscosity still decreased, where the optimum electric field was at 36.67v/cm, as mentioned previously in the Optimum conditions results. The lesser value of viscosity was 12.09159 costs, which means that the best viscosity reduction obtained from this experiment amounted to about 61.856%. This observed a decrease in viscosity because when the crude oil passes the electric field, the paraffin's particles and suspended asphalting were polarizing and aggregating into short chains, resulting in low viscosity. Figure 5 shows the effect of the electrical field intensity on the crude oil's kinematic viscosity.

Table 4: Effect of dual treatment (dilution and Electric Field) on fluid flow characteristics.

EXp. No	Operation variables		Kinematic Viscosity (cSt)	Dynamic viscosity (cP)	Reynolds number (-)	Shear Stress (Pa)	Pressure Drop (Pa)	Power (Watt)	Viscosity reduction (VR %)
	Voltage (volt) (x1)	*Acetone Concentration (Wt. %) (x2)*							
1	140	0	28.99	24.72	204	0.633	88.303	20.777	8.54
2	140	10	18.38	15.678	322	0.401	55.939	13.162	42.01
3	140	20	20.87	17.802	283	0.456	63.612	14.967	34.16
4	180	0	25.75	21.96	230	0.562	78.399	18.446	18.77
5	180	10	14.73	12.56	402	0.321	44.779	10.536	53.53
6	180	20	19.11	16.3	310	0.417	58.171	13.687	39.7
7	220	0	20.41	17.41	290	0.446	62.217	14.639	35.61
8	220	10	13.02	11.10	455	0.284	39.618	9.321	58.92
9	220	20	17.87	15.24	331	0.390	54.405	12.801	43.62
10	180	10	14.73	12.56	402	0.321	44.779	10.536	53.53
11	180	10	14.73	12.56	402	0.321	44.779	10.536	53.53
12	180	10	14.73	12.56	402	0.321	44.779	10.536	53.53
13	180	10	14.73	12.56	402	0.321	44.779	10.536	53.53
14	180	10	14.73	12.56	402	0.321	44.779	10.536	53.53

Table 5: Summary of polynomial coefficients results for different objective functions

polynomial coefficients	Kinematic viscosity	Reynolds number	Shear stress	Pressure drop	Power consumption
a_0	50.44892	-48.1202	1.107500	154.4985	36.35278
a1	-0.17918	2.2169	-0.003985	-0.5560	-0.13083
a2	-2.32761	32.0789	-0.050813	-7.0883	-1.66787
a3	0.00349	-0.0238	0.000076	0.0105	0.00248
a4	0.00020	-0.0024	0.000005	0.0007	0.00015
a5	0.07058	-1.2235	0.001545	0.2155	0.05071
Correlation coif. (R)	0.99657739	0.98711713	0.99660543	0.99660481	0..99322999
Proportion of variance	0.99316649	0.97440022	0.9932222	0.99322115	0..99322999

Reynolds number (Re) is much related to viscosity. Re was increased with the decrease in viscosity. High values have been acquired as 470.662 at optimum electric field intensity. This means that the type of fluid flow is located in the region of laminar flow so the fluid particles move along a well-defined streamline or paths, such that all the streamlines are straight and parallel to each other because of the rearrangement regarding solid particles as well as flow regulation with the minimal resistance to flow in crude oil, resulting in fast transportation without changing its velocity. Figure 6 shows the effect of electric field intensity on Reynolds number values.

The shear stress values are influenced by crude oil viscosity. It represents the resistance to flow near the walls of the pipe where friction occurs. Shear stress has been noticeably reduced with an increase in the electric field intensity affected by the viscosity of crude oil, whereas the minimal value of the shear stress resulted at optimum electrical field intensity as 0.276 Pa. This is because viscosity is defined as the amount of gradual deformation caused by shear stress so if viscosity decreases, deformation is low. As a result, the shear stress values are decreasing. Figure 7 shows the impact of electric field intensity on shear stress at the optimum conditions.

The loss of flow energy due to fluid friction with internal pipe walls is known as pressure drop. Low viscosity causes minor pressure drops, while high viscosity causes massive pressure drops and energy dissipation in the fluid flow. Figure 8 illustrates the effect of electric field intensity on pressure drop values at optimum conditions. From the figure we can show that the pressure drop at the lowest viscosity has been reduced to 38.572 Pa.

Table 6: Optimum conditions results

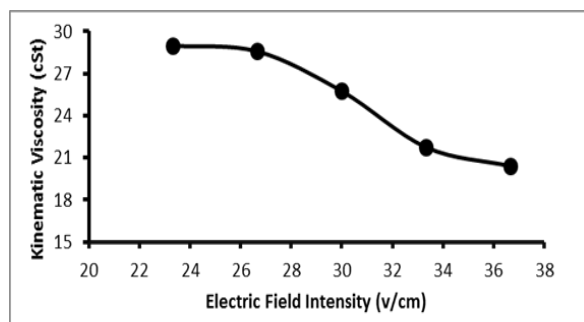| Voltage (volt) (x1)	Acetone Concentration (Wt. %) (x2)	Kinematic Viscosity (cSt) (y)	Viscosity reduction VR%
220	11	12.09159	61.856

Figure 4: Viscosity of crude oil at a different value of electric field intensity
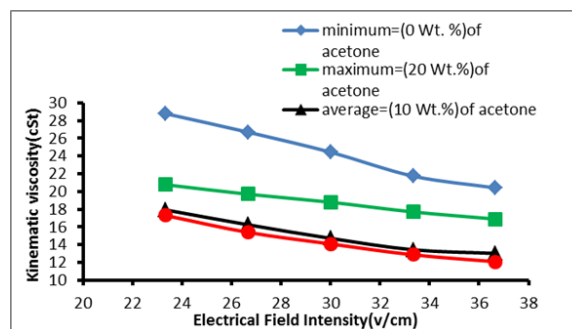

Figure 5: Effect of electric field intensity on the kinematic viscosity of crude oil at different acetone concentrations
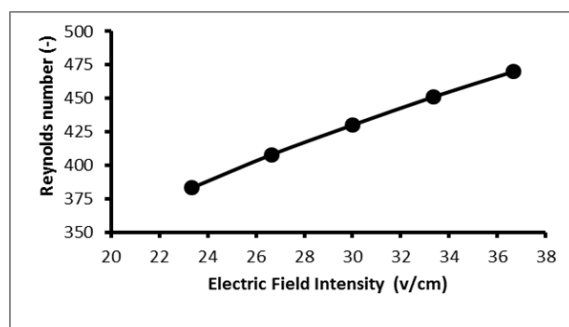

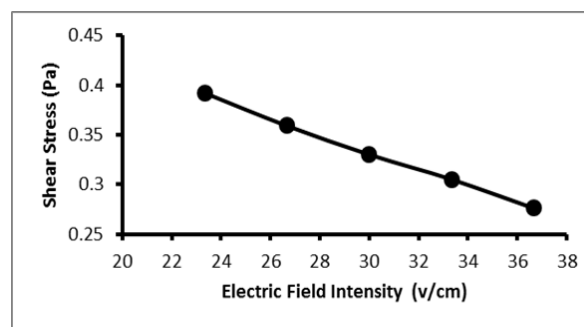**Figure 6:** Effect of electrical field intensity on Reynolds number at 11 wt. % of acetone

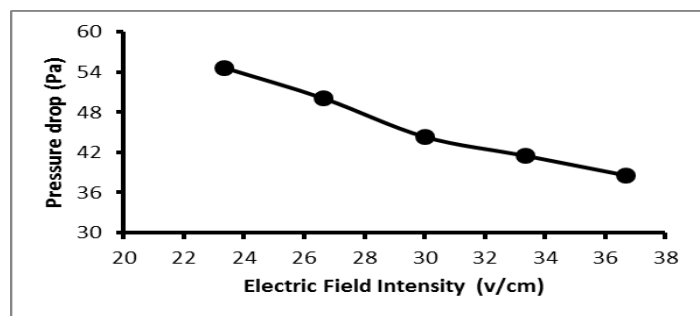**Figure 7:** Effect of electrical field intensity on shear stress at 11 wt.% of acetone

Figure 8: Effects of electric field intensity on Pressure drop at 11 wt.% of acetone

Power consumption is the main issue of energy in transportation via pipelines. Furthermore, such an issue is associated with the fluid viscosity that will be pumped; thus, the low value related to the consumed pumping power was acquired at low viscosity as 8.61 Watt at an optimum value of electrical field intensity. Figure 9 illustrates the effect of electric field intensity on Power consumption values at optimum conditions.

5.3.2 Effect of dilution (acetone concentration):

In this experiment, the reduction of viscosity occurs due to two major factors: electric field intensity effect and dilution effect. Newtonian activities were observed at a constant shear rate of $25.63s^{-1}$. The value of the acetone concentration has a noticeable effect on viscosity reduction; however, as the diluent ratio increases from 0 wt. %to 11 wt. %, the viscosity reduction is still enhanced, with various electrical fields. But in an optimum electric field that is equal to the maximum value (36.67v/cm) as mentioned, the lesser value of viscosity was 12.09159cSt at 11wt. %, of acetone which means that the best viscosity reduction obtained from this experiment amounted to about 61.856%. At optimum conditions; after this11Wt.%, the viscosity is increased with an increase of diluent concentration until got to 17.74cSt at 20wt.%The reason for this behavior is due to the extent of interaction between experimental variables.

The effect of acetone concentration on Kinematic viscosity reflects its effect on values of fluid flow characteristics such as Reynolds number (Re) which is an indication for flow quality and type of flow, Shear stress which is a function of friction and viscosity, pressure drop which is a result of friction augmentation, and finally the power consumed for crude oil pumping which is extremely subordinate on pressure drop effect on the rheological of heavy crude oil flow. Figures (11 –14) show the effect of acetone concentration (Wt. %) on values of Fluid Flow Characteristics.
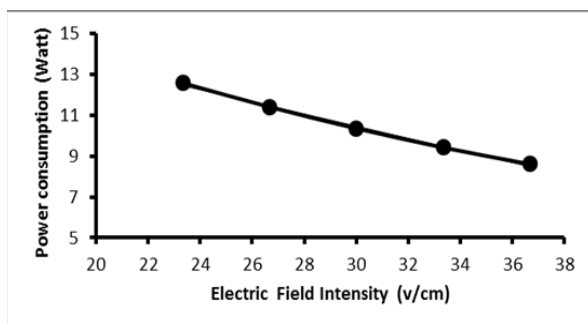
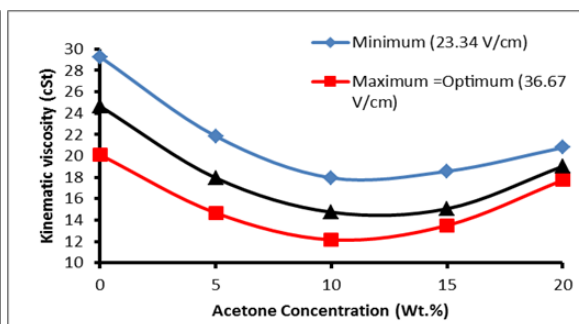**Figure 9:** Effects of electric field intensity on Power consumption at 11 wt.% of acetone

Figure 10: Effect of acetone concentrations on the kinematic viscosity of crude oil at a different electrical field intensity
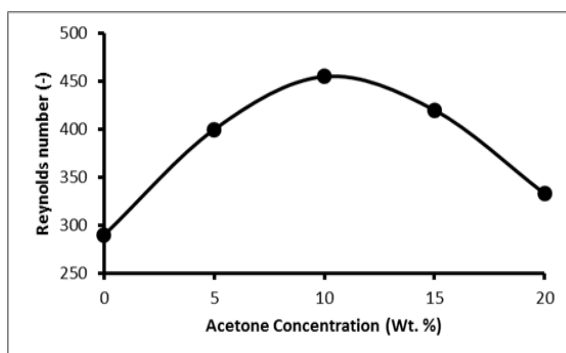

Figure 11: Effect of different acetone concentrations (wt. %) on Reynolds number at 36.67v/cm electric field intensity (optimum condition)
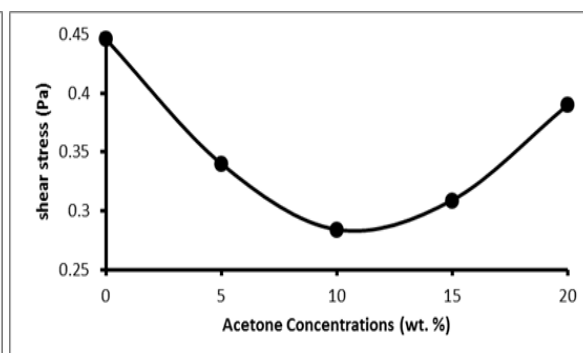
Figure 12: Effect different acetone concentrations (wt. %) on shear stress at 36.67v/cm electric field intensity (optimum condition)
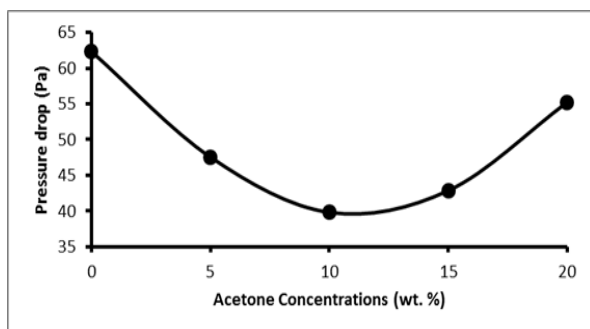

Figure 13: Effect different acetone concentrations (wt. %) on pressure drop at 36.67v/cm electric field intensity (optimum condition)
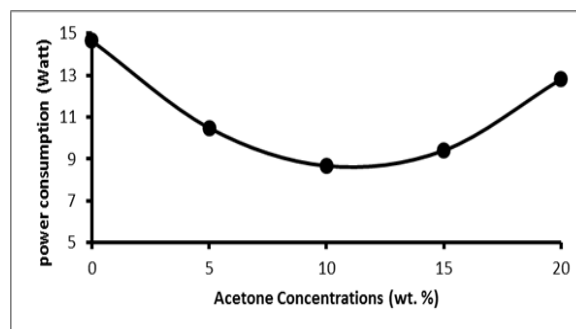
Figure 14: effect different acetone concentrations (wt. %) on power consumption at 36.67v/cm electric field intensity (optimum condition)

5.3.3 Effect of experimental Variables Interaction

The factorial design of experiments, as an optimization technique, allows investigating the effect of experimental variables' interaction on the viscosity reduction shown by the contour map in figure 15. A 3D contour indicates the region of minimum viscosity as a dark green region bounded between 10 and 14 wt.% of diluent and 35 to 38 V/cm intensity represented the cost-effective operating conditions to be used in practical applications.
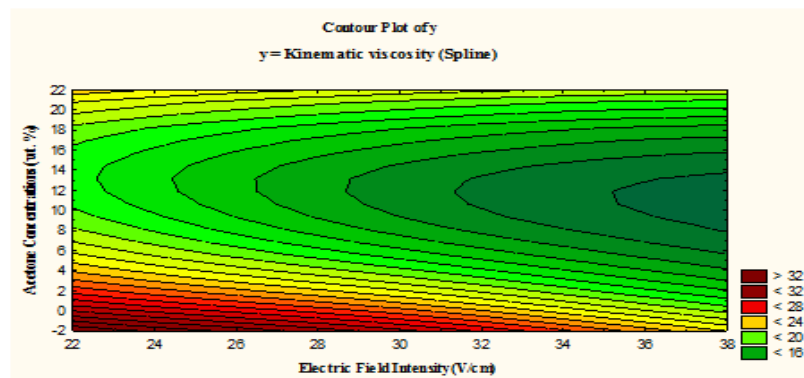
Figure 15: Contour plot of kinematic viscosity, versus acetone concentrations (Wt.%), and electric field intensity (V/cm)

6. Conclusions

The major objective of this study is reducing the viscosity and enhancing the flow related to heavy crude oil via pipelines using dual treatment as electrical field and dilution, the results indicate that:

1)   The dilution's impact (without using electric field) on the Iraqi crude oil's viscosity by using acetone as diluent in different concentrations (0, 5, 10, 15, and 20wt.%), The results show that the maximum viscosity reduction is about 21.98 % when adding 20 wt.% of acetone.

2)   The effect of the electric field (without dilution) showed that the lower value of viscosity 20.41 cSt is obtained when applied electric field equal to 36.67(v/cm). Therefore, the maximum viscosity reduction is about 35.6%.

3)   The effect of dual treatment (dilution and electric field) proved to be a good solution to improve the flow and reduce the viscosity by a cost-effective method reduced the viscosity of crude oil has been effectively by 61.856%. At 36.67V/cm electric field intensity and 11 wt. % of acetone. This viscosity variation is because of particle aggregation.

4)   The optimum conditions were obtained using STATISTICA and WinQSB software's. At optimal conditions, the values regarding shear stress, Reynolds number, power consumption, and pressure drop have been 0.276 (Pa), 470 (-), 8.61(Watt), and 38.572 (pa) respectively.

Nomenclature

d	Diameter of the pipe (cm)	VR	Viscosity reduction
l	pipe's length (cm)	ΔP	pressure drop (Pa)
m	number of constraints	ρ	crude oil density (gm/cm3)
n	number of variables	μ	dynamic viscosity (cP)
Re	Reynolds number (-)	v	Kinematic viscosity(cSt)
Rw	Shear Stress (Pa)	$\acute{y}$	shear rate (sec-1)
P	power consumption (Watt)	γ	pumping efficiency (-)
Q	Volumetric flow rate (cm3/s)	ΔP	pressure drop (Pa)
u	velocity (cm/sec)	ρ	crude oil density (gm/cm3)

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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