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INCREMENTAL ECONOMIC ANALYSIS OF USING DEMULSIFIER TO ENHANCE EFFICIENCY OF RETROFITTED THREE-PHASE GRAVITY SEPARATOR

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ABSTRACT
Incremental economic analysis of using a demulsifier to enhance the efficiency of a three-phase separator was carried out. This was done because the current produced oil contains more water content than the design specification of the three-phase separator which resulted in experiencing separation inefficiency. Therefore, an injection system was installed so that a demulsifier could be injected to increase the rate of phase separation. In addition, two functional 3-in. outlet water pipes were replaced with 4- and 6-in. pipes to compensate for the third non-operational 3-in. outlet water pipe. This was to ensure adequate and timely discharge of the separated water. The results showed that, with highest used demulsifier concentration, the crude oil content in the separated oil phase increased from 67.4 to 85.5%, 78.5 to 98.1% and 88 to 99.9% respectively in the 3, 4 and 6-inch water outlet pipe diameters respectively. Regarding the economic benefits, the discounted incremental pay back periods at different demulsifier concentrations ranged from 3.14 to 3.94 days, 2.29 to 4.18 days and 2.47 to 5.86 days for 3-, 4- and 6-in. water outlet pipes respectively. The incremental net present value at different demulsifier concentrations ranged from about $10.7 to $29.2 million, $18.6 to $29.9 million and $17.3 to $17.6 million for 3-, 4- and 6-in. water outlet pipes respectively at the end of the 10-year operation. Similarly, the rate of return on incremental investment also ranged from 8,356 to 10,486%, 9,587 to 14,387% and 5,623 to 13,369% for 3-, 4- and 6-in. water outlet pipes. Overall, all the used profitability indicators showed that the retrofit has high economic viability.
Keywords: *Three-phase separator, retrofit, economic analysis, profitability indicators, demulsifier.*

INTRODUCTION
An emulsion, which is a common problem in the oil industry, is a colloidal dispersion of one liquid (often referred to as dispersed, internal or droplet) phase in another liquid (normally referred to as continuous) phase. The common types of emulsion are water-in-oil (when the dispersed phase is water and the continuous phase is oil) emulsion, oil-in-water (when the dispersed phase is oil and the continuous phase is water) emulsion and complex/multiple (when oil and water form more than two phases) emulsion (Issaka *et al*., 2015). The process of breaking the emulsion into separate oil and water phases is known as demulsification and this can be achieved by using thermal, mechanical, electrical, chemical, membrane, centrifuge, microbial, air floatation, ultrasonic and microwave methods (Oji and Opara, 2012; Nour and Anisa, 2012; Issaka *et al*., 2015). Water-in-oil emulsion is the most common and therefore its demulsification has attracted more attention than that of oil-in-water emulsion, which is usually encountered only in aging oil fields characterized by high water content. However, several published works regarding the demulsification of crude oil-in-water emulsion can still be found. Some of these work are Bendjaballah *et al.* (2010), Azizi and Nikazar (2015), Zolfaghari, *et al.* (2016), Meybodi, *et al.* (2017), Vallejo-Cardona *et al.* (2017) and Liu *et al.* (2018).

Three-phase separators are vital units in the oil and gas production chain. Essentially, the function of the three-phase separator is to separate the liquid phase of the upstream two-phase separator which still contains the dissolved gas, into three phases: gas, water and oil phases (Ahmed *et al.*, 2017). There are different types of three-phase separators but the most commonly used type is the gravity settling or gravity-based separators because of their ability to provide a sufficient residence time that allows the separation of even liquid droplets (Arnold and Stewart, 2008; Kharoua *et al*., 2013).

One of the ways to improve the efficiency/performance of existing chemical plants is through retrofitting. The term retrofitting refers to an addition (or repositioning or even removal) of a piece of equipment to an existing process plant in order to improve the performance of the process (Turton *et al*., 2009). It is very common in chemical process industries, sometimes using pinch technology, to achieve debottlenecking, optimization and energy utilization (Nelson and Douglas, 1990; Yoon *et al*., 2007; Friedler, 2010; Bhalerao *et al*., 2011; Mohammed *et al*., 2015; Akgun and Ozcelik, 2017). In the case of Oil Mining License (OML)-124 three-phase separator, the retrofitting was carried out so that it can be able to handle a feed whose composition is different from the design feed specification. Because of the aging of the oil wells and associated factors, the water content of the currently produced oil has become too high for the existing separator to handle. Hence, there is need for the addition of an injection system for the injection of demulsifier to increase the rate of phase separation and replacement of the two 3-in. water outlet pipes with larger sizes (4- and 6-in. diameters) to compensate for third non-operational 3-in. water outlet pipe. Figure 1 presents the schematic diagram of the modified three-phase separator.

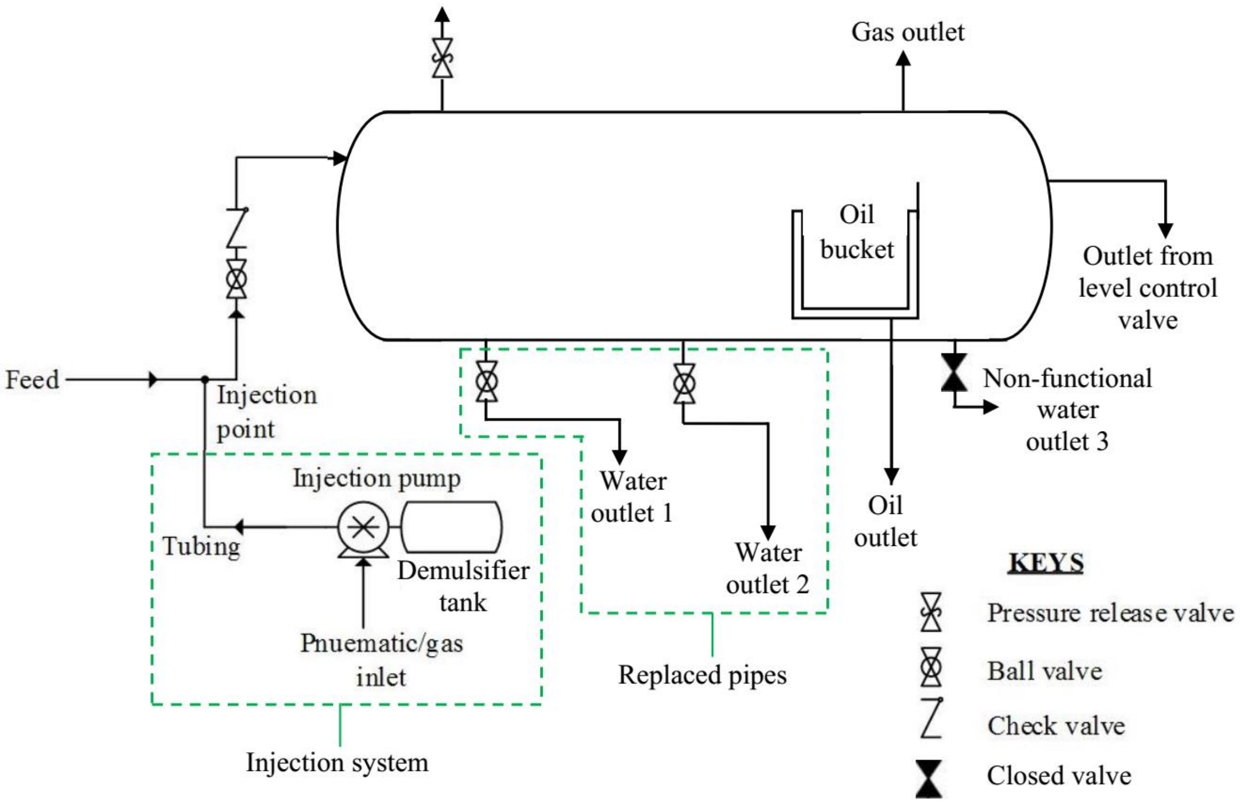

Figure 1: Schematic diagram of the modified three-phase separator

The success of any new or retrofitted chemical plant is majorly assessed through economic/profitability analysis. The basic techniques involve both capital expenditure and yearly operating costs. The profitability criteria are essentially three: time, cash and interest rates. These criteria in most cases are evaluated using discounted techniques especially for large projects because of the importance of time value of money (Turton *et al.*, 2009; Mu'azu *et al.*, 2009; Nguyen and Demirel, 2013). Usually, the cumulative cash flow diagram (CFD) is more convenient than the discrete CFD and it is assumed that any new land purchases are done at the start of the project, that is, at time zero.

For the economic analysis of retrofit projects, it is necessary to identify all of the costs and savings associated with the retrofit, and attention should be focused on the profitability of the incremental investment required. Therefore, the main aim of this study is to carry out profitability analysis of using demulsifier to enhance efficiency of retrofitted three-phase gravity separator in order to quantitatively determine its economic viability.

MATERIALS AND METHODS

Materials

The well fluids used for this study was from OML-124 Izombe ($5^0$38′0″N $6^0$52′0″E) oil field in Imo State, Nigeria. It consisted of gas, crude oil and water and the liquid phase of the well fluids contained over 90% of water because of the aging of the oil well. The chemical demulsifier used for this study was a mixture of polymeric materials and it had a commercial or product name of PC9001. It was classified as oilfield chemical and it was marketed by Production Chemical Group of Companies and was supplied in drums.

Methods

The detailed descriptions of the existing three-phase separator, installed injection system and outlet water pipes, experimental procedures, measurement of the crude oil contents as well as the results obtained have already published (Abubakar and Shuwa, 2009). Meanwhile, it is worth reemphasizing that a pneumatically operated 5100 series texsteam chemical injector pump (Model No: TC-251) was used in the injection system to deliver the demulsifier into the feed of the three-phase separator while a L-k centrifuge machine (Model No: C-4-220-C) was used to measure the oil contents of the feed and the products. Therefore, this incremental economic analysis was based on results presented in the published work. In addition, the method provided by Turton *et al.* (2009) was adopted in this analysis.

Assumptions

The following assumptions were made in carrying out the economic analysis of this work. Except the cost of the crude oil, all the remaining assumptions were made using Turton *et al.* (2009) as a guide.

1. Price of crude oil was fixed at $60 per barrel
2. The plant was to be run for 300 days in a year to allow for maintenance and other unforeseen challenges that will lead to shut down.
3. The purchased equipment life (pump, pipes and tubing) was assumed to be 6 years.
4. The salvage value of the equipment of zero and straight-line depreciation method were assumed.
5. Cost of land for the additional equipment was assumed negligible.

6. Maintenance and utility consumption were assumed take 10% of the gross revenue.
7. The project life was assumed to be 10 years after the modification of the three-phase separator.
8. The tax rate was taken as 45% and the discount rate as 10%.

Cost of equipment and materials
Table 1 presents the cost estimates of all the pieces of equipment and materials used in this study. Except the cost of natural gas, all the remaining costs were sourced from foreign companies that produce these equipment and materials.

Table 1: Costs of equipment and materials

Equipment and materials	Cost (USD $)	Source
12 ft of 3-inch carbon steel pipe	100.17	Permanent Steel Manufacturing Co. Ltd, China
12 ft of 4-inch carbon steel pipe	152.85	
12 ft of 6-inch carbon steel pipe	250.95	
3-inch flanges	50	
4-inch flanges	70	
6-inch flanges	100	
5.2 ft of 3/8-inch stainless steel tubing	18.5	
3-inch flanges	50	
Texsteam chemical injector pump	2300	Teltherm Instrument Ltd, New Zealand
Demulsifier (one drum)	520	Production Chemical Group of Companies, UK
Natural gas per Mcf	2.99	Assumed using International Market price as a guide

Profitability Indicators
The following are the profitability or economic indicators considered in this work.

Incremental pay bck period (IPBP): This is the time required, after start-up, to recover the incremental total capital investment (ITCI) for the project. It is the number of years it takes for the total cash flow to be equal to the total capital investment (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

Commulative incremental cash position (CICP): It is simply the worth of the project at the end of its life. In other words, it is the cummulative cash flow at the end of the project's life (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

Commulative incremental cash ratio (CICR): It is the ratio of the sum of all the positve incremental cash flows to the sum of all the negative incremental cash flows (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

$$CICR = \frac{Sum\ of\ all\ the\ positive\ incremental\ cash\ flows}{Sum\ of\ all\ the\ negative\ incremental\ cash\ flows} \quad (2.1)$$

It is used for comparing projects with disimilar fixed capital investments.

Rate of return on incremental investment (ROROII): It represents the nondiscounted rate at which money is made from the total incremental total capital investment (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009). Mathematically,

$$ROROII = \frac{Average\ incremental\ annual\ net\ profit}{Incremental\ total\ capital\ investment\ (ITCI)} \quad (2.2)$$

Discounted incremental pay back period (DIPBP): It is the time required, after start-up, to recover the incremental total capital investment (ITCI) required for the project, with all cash flows discounted back to time zero (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

Incremental net present value (INPV): It is the cumulative discounted cash position or worth at the end of the project (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

Incremental present value ratio (IPVR): It is also the ratio of the sum of the present values of all the positive incremental cash flows to the sum of the present values of all the negative incremental cash flows (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

$$CIC = \frac{Sum\ of\ the\ present\ values\ of\ all\ the\ positive\ incremental\ cash\ flows}{Sum\ of\ the\ present\ values\ of\ all\ the\ negative\ incremental\ cash\ flows} \quad (2.3)$$

It is also used for comparing projects with different investment levels.

Incremental internal rate of return (IIRR): It is the interest or discount rate for which the incremental net present value of the project is equal to zero. In other words, it represents the highest after-tax interest or discount rate at which the project can just break even (Turton *et al.*, 2009; Mu'azu, *et al.*, 2009).

RESULTS AND DISCUSSION
Table 2 shows the values of profitability indicators for the addition of the demulsifier to the three-phase separator feed in the exiting three-inch water outlet pipes while Tables 3 and 4 present the values of profitability indicators for the addition of the demulsifier to the feed and for replacing the existing three-inch water outlet pipes with four- and six-inch pipe diameters respectively. In general, it can be seen that all the values of the profitability indicators are positives and therefore implied that the project is economically viable and

it is worth the investment. Specifically, the incremental pay back periods were in few days, ranging from about 4.3 days to about 6.4 days. This shows that the additional times required to recover the additional total capital investment are very short. As expected, the values of the discounted incremental pay back periods were slightly longer than their corresponding undiscounted values. Similarly, the values of the cumulative incremental cash positions were also higher than their corresponding incremental net present values. The reason for these trends can be attributed to the time value of the money.

Meanwhile, careful observation of the trends of the profitability indicators with respect to the increase in the demulsifier concentration reveals that those in Table 2 run in contrast with those in Tables 3 and 4. This can be attributed to the additional capital investment to purchase the 4- and 6-inch pipes. Also, in Table 2, there is a change in the trends after demulsifier concentration of 15.05 ppmv for all the profitability indicators. The reason for this change is that the increase in the quantity of the separated oil by increasing the demulsifier concentration from 15.05 to 17.79 ppmv was very small (Abubakar and Shuwa, 2019) and therefore, the increase in the revenue could not offset the additional investment that was incurred from the increase in the demulsifier concentration.

It can also be seen that the rate of return on incremental investments and the incremental internal rate of return were all greater than 100%. In fact, they were all in tens of thousands of percentages, which ordinarily seem to be outrageous. However, the fact that this is an incremental economic analysis which is based on only the additional investment (and not the total investment of the entire plant) makes the values of both profitability indicators reasonable (Nelson and Douglas, 1990). Finally, it should be noted that the cumulative incremental cash ratios and the incremental net present value ratios are less important in this work as there were no comparisons of different projects with dissimilar investments according to Turton *et al.* (2009).

Table 2: Profitability indicators at different demulsifier concentrations for three-inch pipe

Profitability indicators	*Concentration of demulsifier (ppmv)*				
	6.84	*9.58*	*12.32*	*15.05*	*17.79*
IPBP (days)	3.59	3.48	3.08	2.86	3.19
CICP (Million $)	19.1	26.8	38.3	49.8	52.3
CICR	838	863	976	1050	941
ROROII %	8356	8609	9742	10486	9395
DIPBP (days)	3.94	3.83	3.38	3.14	3.51
INPV (Million $)	10.7	14.9	21.4	27.8	29.2
IPVR	514	530	600	645	578
IIRR (%)	8365	8620	9750	10500	9400

Table 3: Profitability indicators at different demulsifier concentrations for four-inch pipe

Profitability indicators	Concentration of demulsifier (ppmv)				
	6.84	*9.58*	*12.32*	*15.05*	*17.79*
IPBP (days)	2.08	2.37	2.58	3.32	3.80
CICP (Million $)	33.2	39.6	46.0	52.4	53.6
CICR	1441	1267	1166	1099	961
ROROII %	14387	12647	11637	10974	9587
DIPBP (days)	2.29	2.61	2.83	3.65	4.18
INPV (Million $)	18.6	22.1	25.7	29.2	29.9
IPVR	885	778	716	675	590
IIRR (%)	14400	12650	11650	11000	9600

Table 4: Profitability indicators at different demulsifier concentrations for six-inch pipe

Profitability indicators	Concentration of demulsifier (ppmv)				
	6.84	*9.58*	*12.32*	*15.05*	*17.79*
IPBP (days)	2.24	3.04	3.82	4.56	5.33
CICP (Million $)	31.1	31.0	31.1	31.4	31.5
CICR	1339	988	786	659	564
ROROII %	13369	9860	7842	6569	5623
DIPBP (days)	2.47	3.34	4.20	5.02	5.86
INPV (Million $)	17.3	17.3	17.4	17.5	17.6
IPVR	822	607	483	405	346
IIRR (%)	13400	9870	7850	6580	5630

CONCLUSIONS

i. The economic analysis of using a demulsifier to enhance the efficiency of a retrofitted three phase separator was carried out and the following results can be drawn from the results.
ii. The highest discounted incremental pay back periods at different demulsifier concentrations were 3.94, 4.18 and 5.86 days in the 3-, 4- and 6-in. water outlet pipes respectively.
iii. The incremental net present values for a project life of 10 years increased with increase in the demulsifier concentrations from about \$10.7 to \$29.2 million, \$18.6 to \$29.9 million and \$17.3 to \$17.6 million in the 3-, 4- and 6-in. water outlet pipes respectively.
iv. The rate of return on incremental investment and the incremental internal rate of return were quantitatively similar and they increased with increase in the demulsifier concentrations in the existing 3-in. water outlet pipes while they showed reverse trend in the 4- and 6-in. water outlet pipes.
v. Overall, all the profitability indicators showed that the retrofitted project was worth the investment.

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REFERENCES

Abubakar, A. and Shuwa, S. M. (2019). Improvement of separation efficiency of three-phase gravity separator at OML-124 Izombe flow station, Imo State. Science Forum (Journal of Pure and Applied Sciences), 16: 48 - 55.

Ahmed, T., Makwashi, N. and Hameed, M. (2017). A Review of Gravity Three - Phase Separators. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 8 (3): 143 - 153.

Akgun, N. and Ozcelik, Z. (2017). Debottlenecking and Retrofitting by Pinch Analysis in a Chemical Plant. American Journal of Energy Engineering, 5 (5): 39 - 49.

Arnold, K. and Stewart, M. (2008). Surface Production Operations. Amsterdam., Gulf Professional Publishing.

Azizi, K. and Nikazar, M. (2015). Characterization of Chemical Demulsification of Oil in Water Emulsion: Comparison Between a Kinetics Model and Laboratory Experiments. Petroleum Science and Technology, 33: 8 - 14.

Bendjaballah, M., Canselier, J. P. and Oumeddour, R. (2010). Optimization of Oil-in-Water Emulsion Stability: Experimental Design, Multiple Light Scattering, and Acoustic Attenuation Spectroscopy. Journal of Dispersion Science and Technology, 31(9): 1260 - 1272.

Bhalerao, Y. P., Patil, S. V., Vijay Babu, P. V. and Kulkarni, S. J. (2011). Energy Retrofit Studies in Diethyl Thiophosphoryl Chloride (DETC) Plant. International Journal of Chemical Engineering and Applications, 2(6): 439 - 444.

Friedler, F. (2010). Process integration, modelling and optimization for energy saving and pollution, reduction. Applied Thermal Engineering 30: 2270 - 2280.

Issaka, S. A., Nour, A. H. and Yunus, R. M. (2015). Review on the Fundamental Aspects of Petroleum Oil Emulsions and Techniques of Demulsification. Journal of Petroleum and Environmental Biotechnology. 6 (2): 1 - 15.

Kharoua, N., Khezzar, L. and Saadawi, H. (2013). CFD Modelling of a Horizontal Three-Phase Separator: A Population Balance Approach. American Journal of Fluid Dynamics 3 (4): 101 - 118.

Liu, D. Suo, Y., Zhao, J., Zhu, P., Tan, J., Wang, B. and Lu, H. (2018). Effect of Demulsification for Crude Oil-in-Water Emulsion: Comparing CO_2 and Organic Acids. Energy and Fuels, 32: 757 - 764.

Meybodi, N. M., Mohammadifar, M. A. Farhoodi, M. Skytte, J. L. and Abdolmaleki, K. (2017). Physical Stability of Oil in Water Emulsions in the Presence of Gamma Irradiated Gum Tragacanth. Journal of Dispersion Science and Technology, 38 (6): 909-916.

Mohammed, H. I., Idriss, I. M. and Highina, B. K. (2015). Retrofitting a single-pressure nitric acid plant using pinch technology. Seminar Series, Faculty of Engineering, University of Maiduguri, Vol. 6.

Mu'azu, K., Okonkwo, E. M. and Abdullahi, M. (2009). Economic Analysis of Production of Essential Oil using Steam Distillation Technology. Nigerian Journal of Basic and Applied Science, 17 (2): 218 - 222.

Nelson, D. A. and Douglas, J. M. (1990). A systematic procedure for retrofitting chemical plants to operate utilizing different reaction paths. Ind. Eng. Chem. Res., 29 (5): 819 - 829.

Nguyen, N. and Demirel, Y. (2013). Economic Analysis of Biodiesel and Glycerol Carbonate Production Plant by Glycerolysis. Journal of Sustainable Bioenergy Systems, 3: 209 - 216.

Nour, A. H. and Anisa A. N. I. (2012). Demulsification of water-in-oil (W/O) emulsion via microwave irradiation: An optimization. Journal of Scientific Research and Essays 7: 231 - 243.

Oji, A. and Opara, C. C. (2012). Electrocoalescence of Field Crude Oil using High voltage Direct Current. International Journal of Engineering Science and Technology, 4: 1850 - 1857.

Turton, R., Bailie, R. C., Whiting, W. B. and Shaeiwitz, J. A. (2009). Analysis, synthesis, and Design of Chemical Processes, 3rd Edition, Prentice Hall, Upper Saddle River, New Jersey, United State.

Vallejo-Cardona, A. A., Martinez-Palou, R., Chavez-Gomez, B., Garcia-Caloca, G., Guerra-Camacho, J., Ceron-Camacho, R., Reyes-Avila, J., Karamath, J. R. and Aburto, J. (2017). Demulsification of crude oil-in-water emulsions by means of fungal spores. PLOS ONE, 12 (2): 1 - 17.

Yoon, S. G., Lee, J. and Park, S. (2007). Heat integration analysis for an industrial etylbenzene plant using pinch analysis. Applied Thermal Engineering, 27: 886 - 893.

Zolfaghari, R., Fakhru'l-Razi, A., Abdullah, L. C., Elnashaie, S. S. E. H. and Pendashteh, A. (2016). Demulsification techniques of water-in-oil and oil-in-water emulsions in petroleum industry. Separation and Purification Technology, 170: 377 - 407.