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# Investigating the Effect of Varying Tubing Air Concentration during the Descaling of Petroleum Production Tubing using Multiple High-Pressure Nozzles

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**Abstract**

Despite the continued research effort on erosion behavior of multiple flat fan nozzles in removing different types of scale deposits from petroleum production tubing, effect of chamber air concentration and nozzles configuration is yet to be given detailed consideration. This study, therefore, considers the utilization of multiple high-pressure sprays at different chamber air concentration to enhance the rate of scale removal from petroleum production tubing. Additionally, options of altering chamber air/water ratio and header configurations for more effective scale removal were explored. Also, the effect of nozzle header arrangements on the removal of paraffin of different stages of deposition in petroleum production tubing is investigated. The selection of chamber air concentration and header configuration (nozzles arrangement) for effective scale removal was found to be governed by the shape and type of the scale deposit. Furthermore, the descaling capacity increases with decrease in number of nozzles due to pressure drop effect irrespective of the type or shape of the scale deposit. This novel descaling experiment of utilizing 10MPa injection pressure from 25mm jetting position averagely removes hollow paraffin deposits that range from 44g to 280g and 34g to 89g of solid shaped paraffin as a result of altering nozzles configuration. Correspondingly, an average removal difference ranging from 48g to 270g of hollow shaped and 35g to 218g of solid shaped paraffin deposit was recorded as a result of compressing the chamber pressure by 0.2MPa and subsequently suctioning it by -0.008MPa respectively.

***Keywords:*** Descaling; production tubing; scale deposit; multiple nozzles.

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## 1. Introduction

The challenge of scale deposition in petroleum production tubing remains the most troublesome among all petroleum production associated problems. Consequently, it is a stumbling block for both flow assurance and energy security till date. Despite the invested money and time to tackle the problem, no solution has proven universal to all types of scale deposits or effective in terms of economic, rig time, ease, and safety for both rig completion and personnel's, and also, the environment [1]. Thereby, limiting treatment options to: aggressive chemical solution like acid utilization in the case of chemical inhibitors and dissolvers [2–4] and destructive mechanical techniques such as explosives, cutters and mills [5]. Others are complete rig workover to replace the tubing or even deferring production [6]. These problems are mostly attributed to the consequence of poor planning and incorporation of scale management strategies (prevention) into asset life cycle management of a field at the CAPEX phase to reduce removal and inhibition cost during the OPEX phase of the field [7]. Notwithstanding, scale deposition is possible either before inhibition deployment or at the end of inhibition treatment life [8], thereby, leaving confrontational emergency/removal response as lone option for the operating companies. The entire flow channels of the production system from the reservoir, wellbore, downhole equipment, production tubing, wellhead to other topside production system are at risk of inorganic scale deposition due to contact with water during field production [9]. Inorganic scale deposit species like calcium carbonate, strontium sulfide and others are mostly attributed to the effect of mixture of incompatible waters from the formation and seawater during water injection and other secondary recovery process [10]. Whereas organic deposits such as paraffin and aliphatic hydrocarbons are as a result of physiochemical and thermodynamic changes of the properties of the produce fluid due to the dynamic nature of hydrocarbon production like, volume, temperature, PH and pressure of the produced fluid [11]. Even though factors like $CO_2$ liberation, flow regime, nature of the surface and hydrodynamics of the system should not be underestimated [12] although, sometimes, the heavy crude production nature of some field is also key to organic scale deposition. The mechanical approach of utilizing high pressure water for scale removal has gained wider acceptance by multinational [13], despite facing poor downhole performance challenges (cavitation) that required abrasion compensation (i.e. sand) to remedy [14] despite its side effect of jeopardizing the integrity of the well completion. While the replacement of sand particle with sterling beads was excellent, with good well completion integrity after descaling at the expense of environmental complexity [15]. The effect of environmental and well integrity complexity side effects of sterling beads couple with cavitation effect toward high pressure jetting lead to the introduction of the recent solid free jetting descaling techniques. The method combines both erosion and stress cycling jetting mechanisms by utilizing aerated chamber with incorporated single high-pressure flat fan nozzles [16]. Although, characterized with high rig time and poor scale coverage.

## 2. Materials and Method

This novel experimental scale removal technique utilizes multiple high-pressure sprays at 10MPa injection pressure from 25mm stand-off distance with different nozzle header configurations for 3minutess experimental run-time to remove the constructed paraffin deposit from the simulated production tubing. The paraffin deposit of different shapes and sizes, shown in **Figure 2.1**, signifying different growth stages of paraffin in production tubings were constructed from household candles (wax) and further subjected to chemical and compositional characterization. This was done through nuclear magnetic resonance (NMR) and Fourier-transform infrared spectroscopy (FTIR) to determine the true chemical representation of actual oilfield paraffin deposit. Furthermore, the constructed and characterized paraffin deposits ware descaled inside a descaling rig that housed the simulated production tubing (the descaling chamber), high pressure water pump and the multiple nozzle header for nozzle/header configurations as shown in **Figure 2.2**. The descaling rig also consists of a vacuum pump and a compressed air system for altering the chamber pressure from -0.008MPa to 0.10325MPa and then, to 0.2MPa.

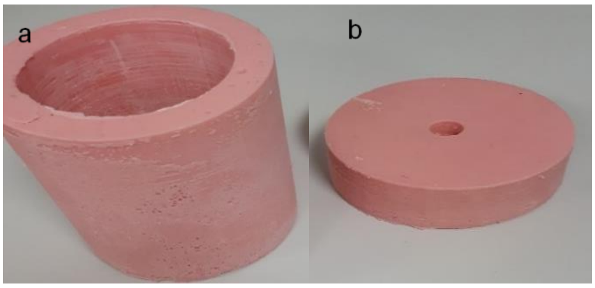



**Figure 2.1:** Constructed soft scale (a) hollow shape, (b) solid shaped samples [1]

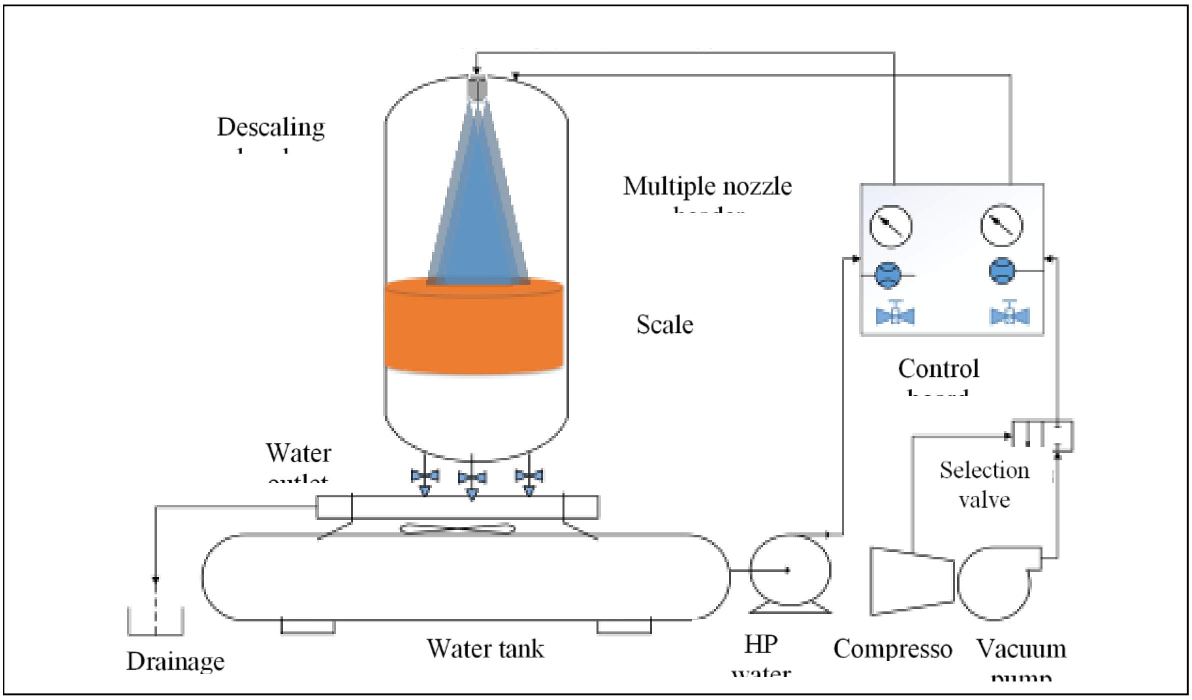



**Figure 2.2:** Descaling rig setup [1]

Also, different number of nozzles are fitted into the nozzle header at different nozzles arrangements in order to find the efficient nozzle configuration for removing paraffin deposits of different shapes. Likewise, both the nozzles and header configurations were done hand in hand by fitting in the desired number of nozzles (3 4, or 5 nozzles) into the header at three nozzle arrangements namely non-centre nozzle arrangement (NCN), centre nozzle arrangement (CN) and centre nozzle overlap arrangement (CNO) arrangement/configuration. Undesired header nozzle sockets were blocked with bank plugs as shown in **Figure 2.3**.

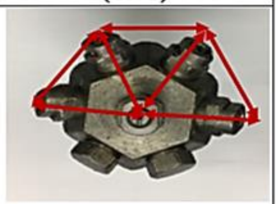
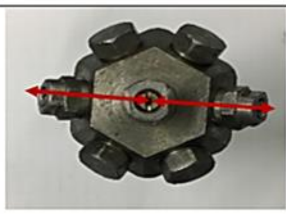
| No of Nozzles | Header/Nozzle Configuration | | |
|---|---|---|---|
| | Non-Centre Nozzle Configurations (NCN) | Centre Nozzles Configurations (CN) | Centre Nozzle Overlap Configurations (CNO) |
| 5 |  |  |  |
| | Pentagon | Envelope | Trapezium |
| 4 |  |  |  |
| | Rectangle | Pyramid | Kite |
| 3 |  |  |  |
| | Triangle | Diagonal | Right-angled |

**Figure 2.3:** Header and nozzle configurations [1]

Additionally, in order to enhance the rate of removing the constructed soft deposit (paraffin) of different shapes from production tubing, the water air ratio of the simulated production tubing was purposely varied. Firstly, both the hollow and solid shape paraffin scale deposits were first removed at ambient chamber pressure by spraying the high-water pump at 10MPa injection pressure from 25mm stand-off distance. Subsequently, the chamber pressure was altered by introducing compressed air of 0.2MPa while simultaneously injecting water at 10MPa or alternatively, by suctioning the chamber pressure to -0.008 MPa while spraying at 10MPa during the 3-minute descaling period. The entire experimental procedure of utilizing ambient water temperature to removed different types of scale deposit from production tubing is detailed in the work [1].

## 3. Results and Discussion

Prior to the commencement of the descaling experiment, the constructed paraffin scale deposits were subjected to chemical and compositional analysis through NMR and FTIR analysis to determine their true chemical representations as earlier mentioned. The utilization of NMR spectroscopy to investigate the chemical similarities of the constructed deposit to that of typical oilfield paraffin deposit yielded the following set of results shown in **Figure 3.1** and confirms the presence of saturated hydrocarbons. The 1H NMR spectra proofs the presence of Olefinic protons between δ= 0.5ppm to δ= 1.5ppm characterized as hydrogen groups of CH, $CH_2$ and $CH_3$ that corresponds with reported spectra in [17]. While the singlet at δ = 0.0ppm and singlet peak at the extreme (δ = 7.278 ppm) are assigned for TMS calibration peak and the deuterated chloroform (CDCl3) solvent that was utilized in dissolving the sample. Moreover, no peak was observed in the δ = 7.0ppm and δ = 8.0ppm aromatic region of the spectra.

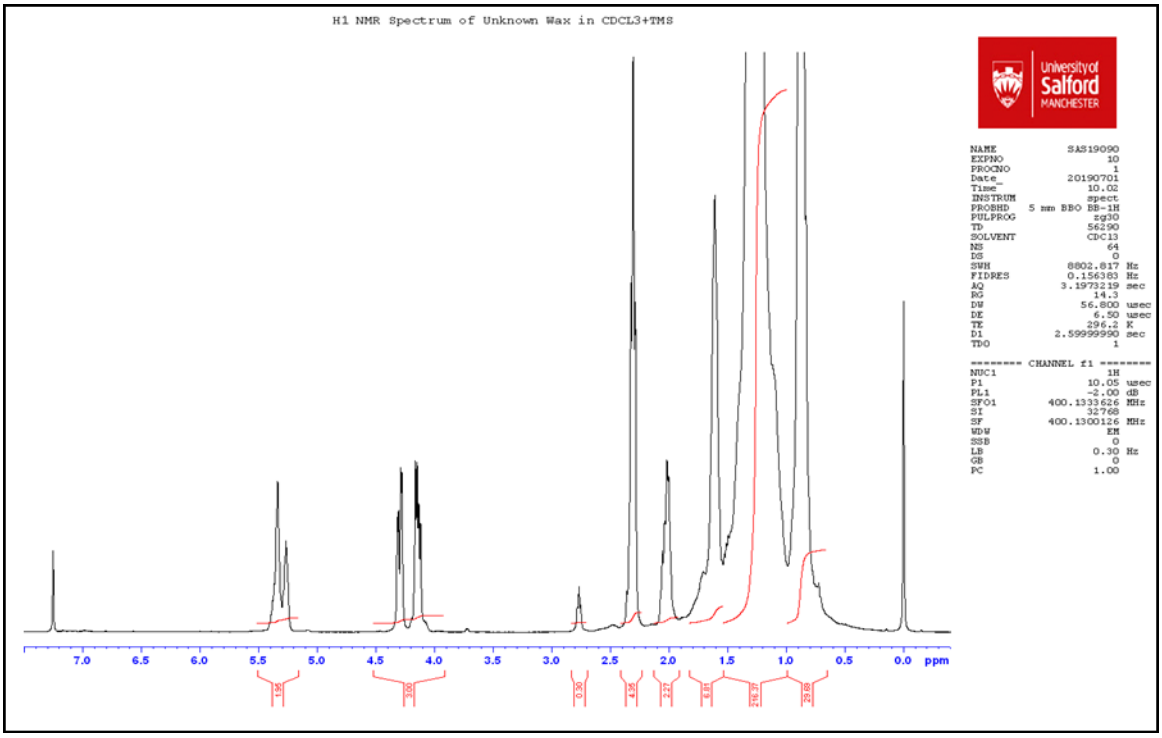



**Figure 3.1:** NMR analysis results [1]

To confirm the NMR results or re-affirm the chemical representativeness of oil field scale chemical compositions in the constructed soft scale samples, the samples were further subjected to Infrared spectroscopy analysis using Thermo Scientific Nicolet iS10 and validated by comparing the generated results via superimposing it with that of paraffin flakes from the system inbuilt archived (database) and liquid paraffin syrup as shown in **Figure 3.2.** The spectra from the generated results reveal similar functional groups to that of oil filed paraffin in terms of finger prints and bands and also the absorption peaks between 2900$cm^{-1}$ and 2800 $cm^{-1}$ allocated for vibration and stretching of $CH_2$ and $CH_3$ proofs the presence of aliphatic paraffin as reported in [18]. Also, it matches the FTIR spectra paraffin result from the National Institute of Standard and Technology (NIST) database.

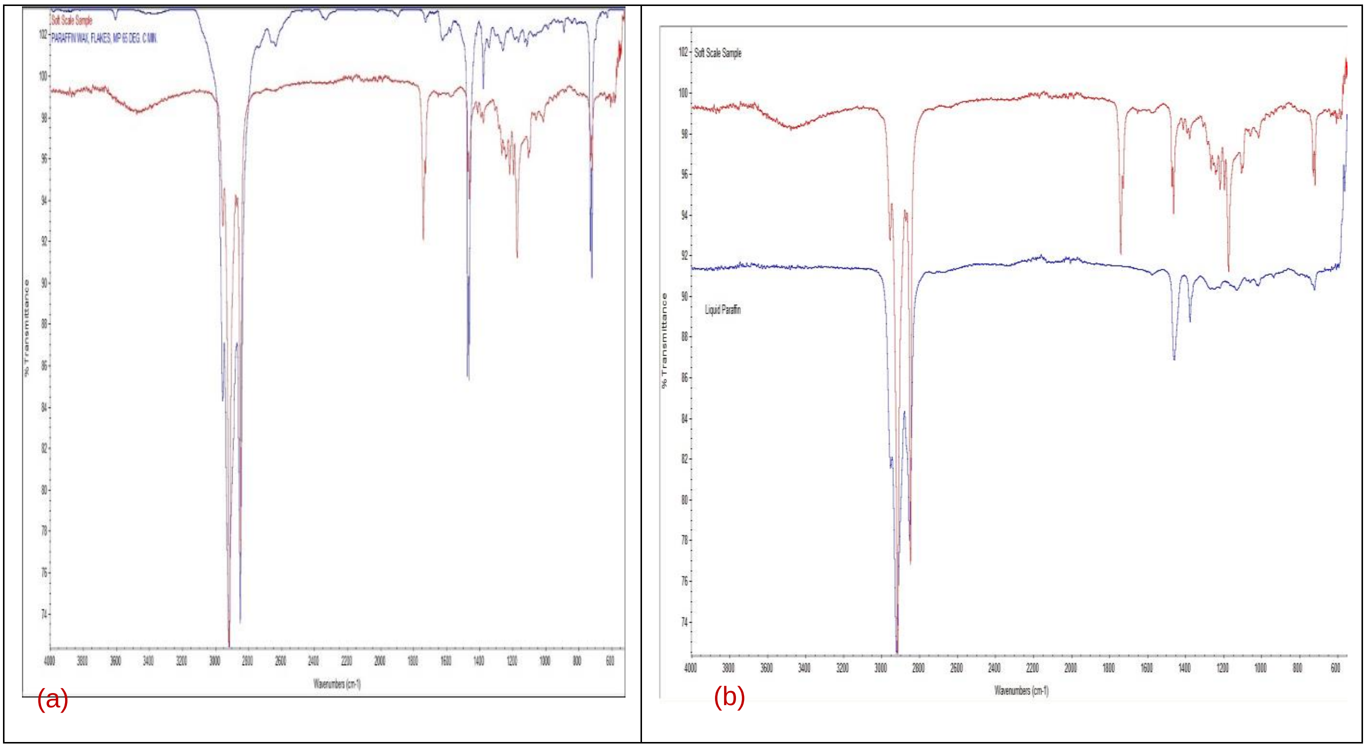



**Figure 3.2:** FTIR analysis result of constructed wax and (a) paraffin flakes and also (b) Liquid paraffin [1]

Generally, despite the two deposits having same chemical properties, their differences in shape and sizes will make them respond to different jetting mechanisms and require unique descaling conditions for their effective descaling [19]. This connects the selection of best descaling parameters of each deposit to its physical properties. Header configuration, in order words, number of nozzles which determine the jet impact that account for the scale removal is proportional to flow rate, injection pressure and inversely proportional to the nozzle area (number of nozzles) due to pressure drop effect. Fewer nozzles will have greater pressure drops that will produce higher velocity jet impact (kinetic energy) to efficiently remove more scale deposit [20]. The effect of pressure drops across multiple nozzles is expressed in Equations 1 and 2. The results of the bucket weighing experiment showing effect of number of nozzles on pressure drop is presented in **Figure 3.3** and the experimental procedure is detailed in [21]. While on the order hand, nozzle arrangement, which is directly connected to the number of nozzles, was found to be governed by the shape and thickness of the deposit in questions. Since the essential requirement for archiving optimal descaling is the complete coverage of the target surface [22]. The non-centre nozzles arrangement (NCN) was found to be more suitable for removing earlier paraffin deposition in production tubing (hollow) due to all the jet impact being diverted to the side nozzles that are in good contact with the deposit. Contrary to centre-nozzle arrangement (CN) that is more efficient in removing complete tubing blockage, due the introduce centre nozzle with higher impact (kinetic energy) spraying directly on the face of the scale deposit in addition to the centre nozzle aiding both particles lifting and abrasion mechanism at the same time. The centre-nozzle overlap arrangement (CNO) was also more suitable for complete tubing blockage even though due to the tubing size constraint, a complete overlap spray profile could not be produced. Also coupled with its highest droplet velocity of the jet concentrating toward the centre of the spray overlap region is been distorted [23]. Also, both the centre nozzle configurations (CN, CNO arrangement) are not suitable in descaling early inflicted production tubing because the introduced centre nozzle will ineffectively spray through the hollowness of the hollow shape scale deposit.

$$P_b = \frac{513.559Q^2\rho}{A^2C^2} \quad (1)$$

Were $P_b$ is the pressure drop (MPa), Q is the flowrate (11.3lt/s), ρ is the density of water (0.98), C is the nozzle discharge coefficient (0.9) and A is total areas of nozzle (0.5mm x number of nozzles).

$$P_{b-5Nozzles} < P_{b-4Nozzles} < P_{b-3Nozzles} \quad (2)$$

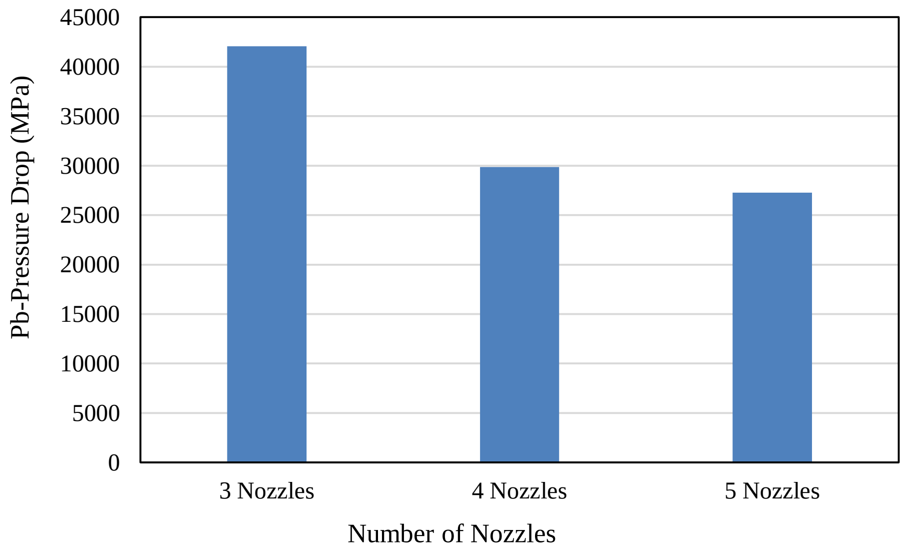



**Figure 3.3:** Bucket Weighing Result

The consequences of altering chamber air pressure (water-air ratio) affect both the jetting mechanisms and the resultant impact of the jet. At ambient chamber air concentration, both the jet strength and all the jetting mechanisms are not altered, while the introduction of the 0.2MP compressed air suppressed the kinetic energy of the jet but aid both cyclic stress and particle abrasion jetting mechanism on the samples. Suctioning the chamber by -0.008MPa increased the kinetic energy of the jet and enhance the hoops stress mechanisms on the samples as in Equation 3.

$$\tau_{hoopVac} > \tau_{hoopAmb} > \tau_{hoopCom} \quad (2)$$

The removal of soft hollow shape scale benefited from the hoop stress mechanism by concurring to the thin walled hoops stress conditions making it slightly more impressive under the (-0.008MPa) vacuum pressure than compressed and far better than ambient condition as shown in equation Equations 4 and 5. While the introduction of 0.2MPa of compressed air into the chamber aided the cyclin stress removal mechanism of the soft solid shape deposit samples due to additional fatigue from the compression [24]. Where P being internal resultant pressure (chamber pressure+ jet pressure), $\tau_{hoop}$ is the hoop stress, $r$ and $D$ are the radius and diameter of the hollow sample and $t$ is its thickness.

$$\frac{Pr}{t} = \tau_{hoop} \tag{3}$$

$$\frac{D}{t} > 20 \tag{4}$$

**Figure 3.4** qualitatively demonstrates an average removal difference of 14g and 22 g between the NCN and CN and also the CNO nozzle arrangements across all the respective chamber pressures. This removal lead by NCN arrangement over the other arrangements is attributed to the absence of the centre nozzle that diverted the jet strength to the side nozzles which are in good contact with scale deposit. While the 48g average initial removal recorded with the ambient condition operation across the respective nozzle arrangements was increased to almost 58g after the introduction of 0.2MPa compressed air . So also, slightly further to 60g due to suctioning of the chamber by 0.008MPa. Similarly, **Figure 3.4** still qualitatively demonstrates how 10MPa injected multiple nozzles sprayed from 25mm stand-off distance could only crack and drilled holes across the respective 5 nozzle arrangements during the ambient hollow paraffin removal. This is contrary to the compressed operation that broke across the 5 nozzles arrangement except for CNO arrangement and complete breakage for all the vacuumed operation 5 nozzles arrangement.

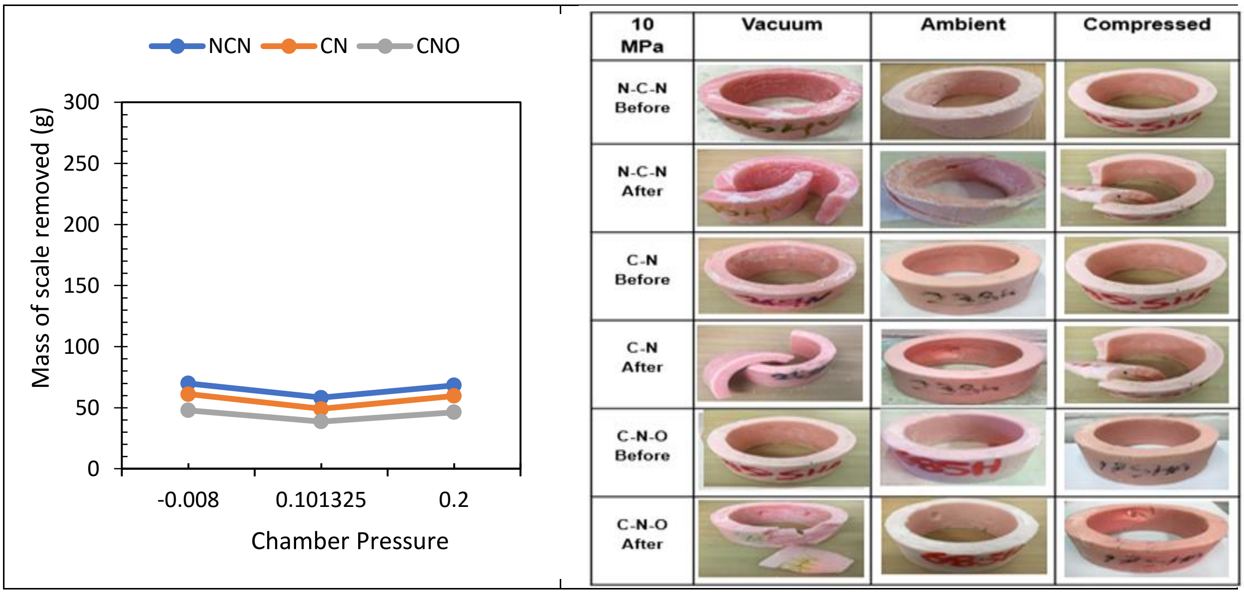



**Figure 3.4:** Descaling hollow shape soft scale at 10MPa with 5 nozzles at 25 mm stand-off distance

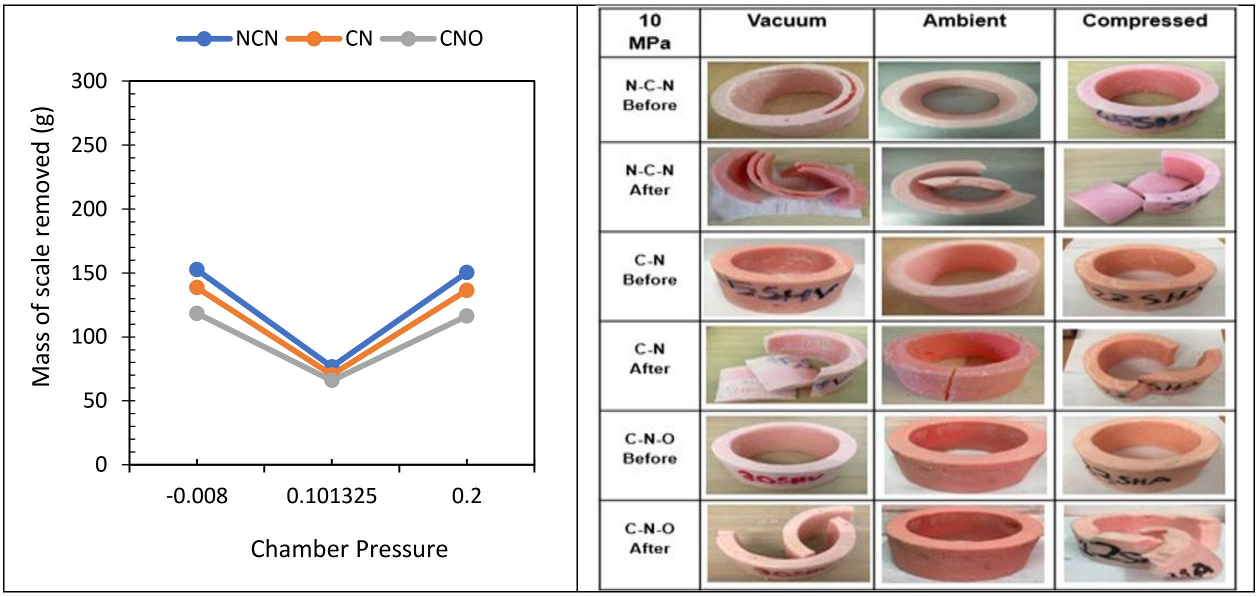



**Figure 3.5:** Descaling hollow shape soft scale at 10MPa with 4 Nozzles at 25mm stand-off distance

Reducing the header nozzles configurations from 5 nozzles to 4 nozzles significantly increased the average initial paraffin deposit removal results of the NCN, CN and CNO arrangements by 61g, 63g and 56g respectively across all the respective chamber pressure due to multiple nozzles drops effect as earlier mentioned. So, also recording a 12g and 27g average paraffin removal lead between the NCN and other respective arrangements and the 71g initial deposit removal recorded with 4 nozzles in ambient condition increases to 134g and 137g after subsequently altering the chamber pressure to compressed and later vacuumed air concentration respectively. Meanwhile, reducing the number of nozzles to 4 nozzles in **Figure 3.5** qualitatively increase the entire removal across all the nozzles arrangement with complete deposit breakage across the compressed condition and more breakage at vacuum air condition due to hoop stress effect. Even though, only the NCN arrangement was able to lead to complete sample breakage during the ambient chamber experiment.

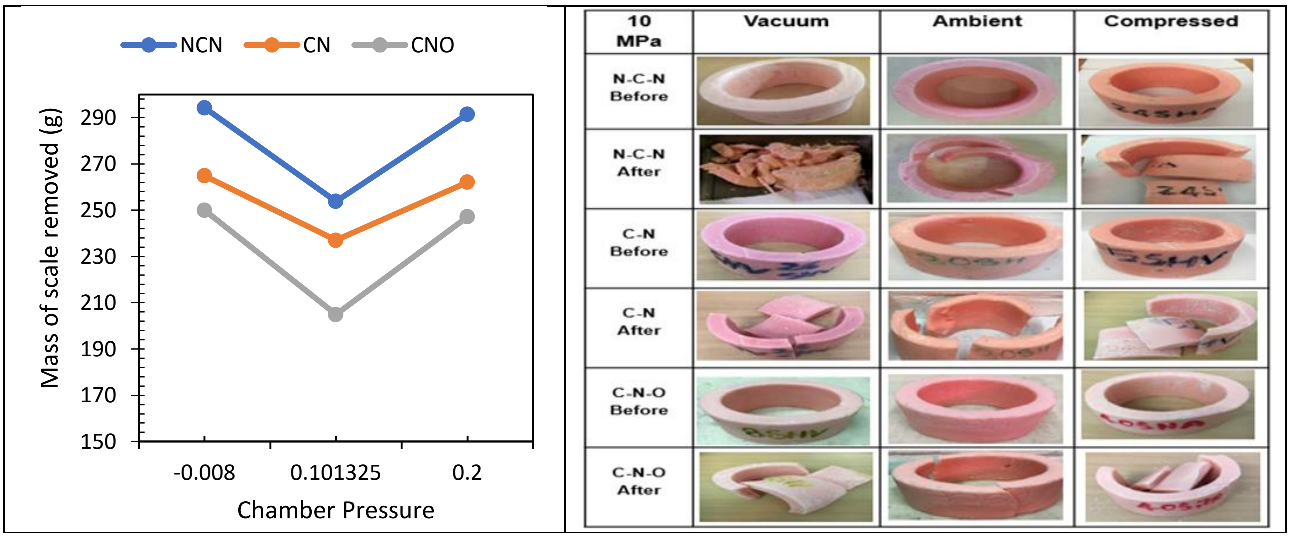



**Figure 3.6:** Descaling hollow shape soft scale at 10MPa with 3 Nozzles from 25mm stand-off distance

Further altering the nozzles configurations to 3 nozzles as quantitatively shown in **Figure 3.6** proved to be the most effective because, the lesser the nozzles the higher the pressure drop effect as suggested by [25]. This leads to a skyrocketing of the 4 nozzles paraffin removal results of the NCN, CN and CNO arrangements by almost 153g, 140g and 134g respectively, while the NCN arrangement still leads the CN and CNO arrangements by 25g and 46g respectively. Likewise, the 232g average paraffin removal result recorded during the ambient operation was improved to 267g and later 270g after altering the chamber pressure to compressed and later vacuum condition. Furthermore, altering the header configuration to 3 nozzles did not only skyrocket the quantitative removal rate across all the configuration but qualitatively recorded a breakthrough, that broke all the sample across the entire chamber pressure and nozzle arrangements as shown in **Figure 3.6**.

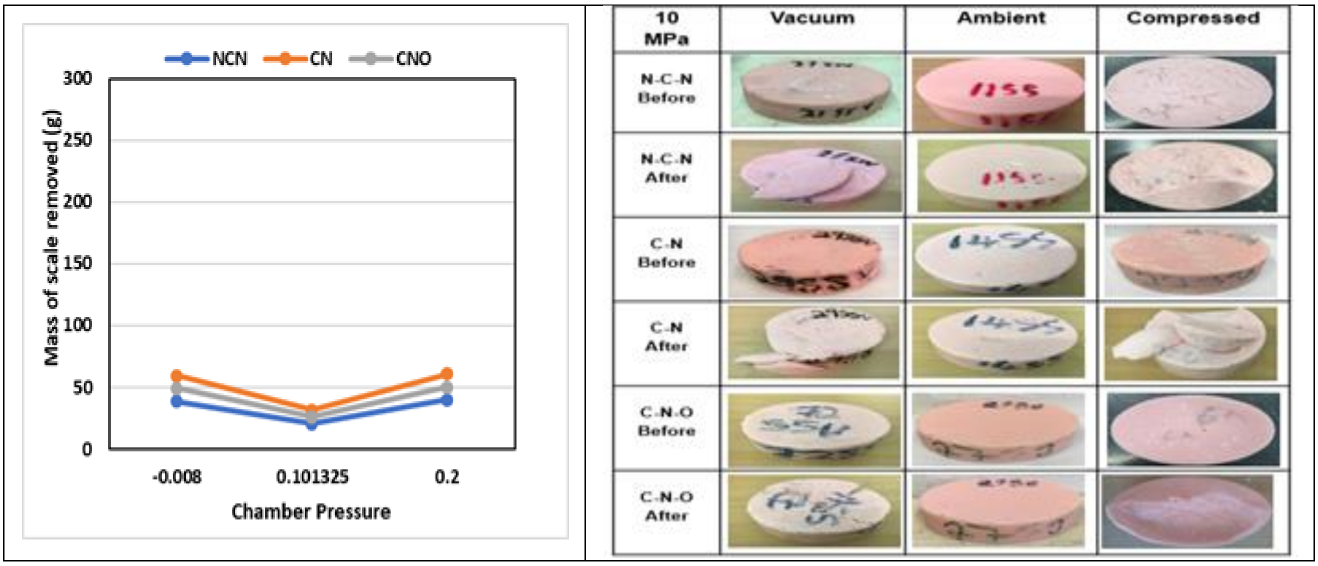



**Figure 3.7:** Descaling hollow shape soft scale at 10 MPa with 5 nozzles at 25 mm stand-off distance

Similar descaling trend was observed with the solid scale removal, even though not effective as hollow removal due to their 30mm thickness difference and this time better off with compressed chamber condition due to the effect of the induced cyclic stress on deposit and centre nozzle arrangement (CN). The impact of altering nozzles arrangement with 5 nozzles at 10MPa to remove solid paraffin shape insignificantly recorded average paraffin removal difference of 8g and 17g between the CN arrangement and CNO and also the CNC arrangement due to the introduced centre nozzle having more jet strength and in good contact with face of the sample. **Figure 3.7** also quantitatively depicts an average ambient removal result of 35g across all the respective nozzles arrangement that was improved to 48g and 50g as a result of compressing the chamber and subsequently suctioning it respectively. Quality-wise, as shown in **Figure 3.7**, an ineffective result across all the nozzle arrangements was recorded with few sample breakages in the compressed and vacuum air condition experiment.

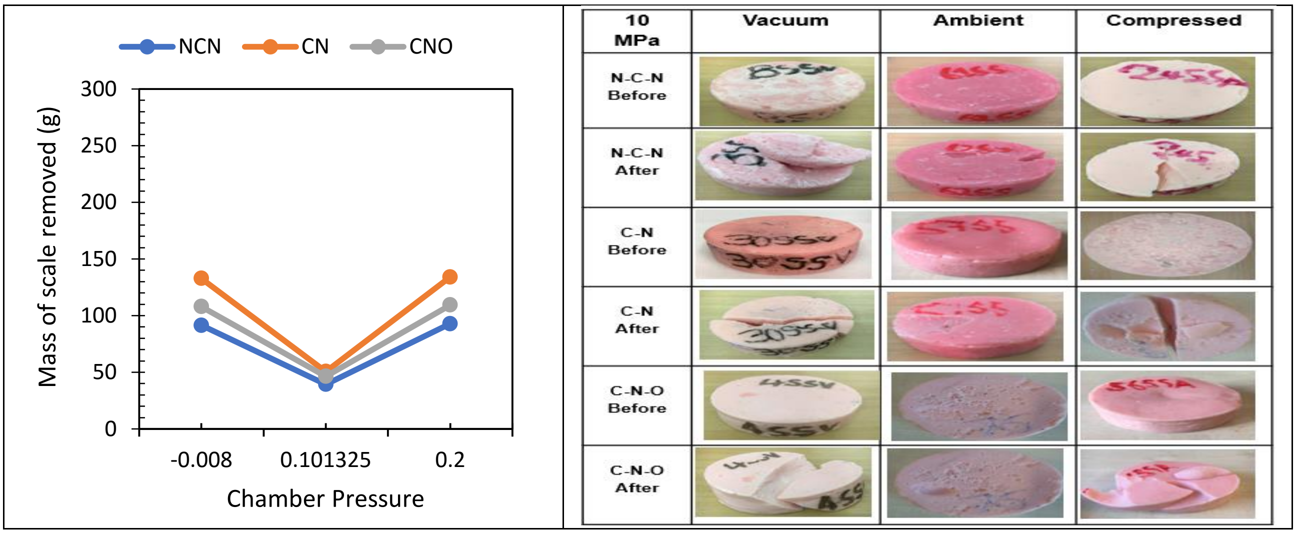



**Figure 3.8:** Descaling hollow shape soft scale at 10 MPa with 4 nozzles at 25 mm stand-off distance

Altering the header configuration by reducing the number of nozzle to 4 significantly doubled the 5 nozzles average removal result by 55g, 45g and 41g across the CN, CNO and NCN nozzle arrangement, with average paraffin removal difference of 18g and 3g as a result of altering nozzle arrangement from CN to CNO and NCN respectively. Also, the average removal value of 46g that was recorded at ambient chamber condition doubled to 112g and 111g due to the consequences of varying the chamber pressure to compressed and later vacuumed condition respectively. A more improved qualitative removal result was also observed after reducing the number of nozzles to 4 by drilling holes across all the nozzle arrangement of the ambient chamber condition and breaking all the descaled samples of the compressed and vacuum chamber conditions as shown in **Figure3.8**.

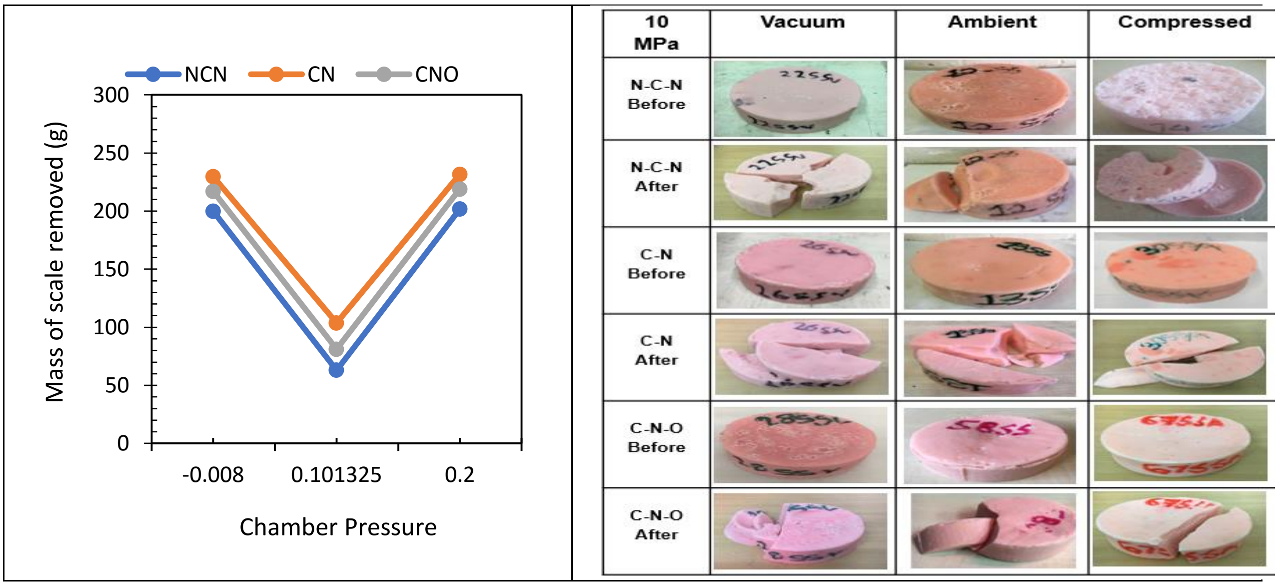



**Figure 3.9:** Descaling hollow shape soft scale at 10 MPa with 3Nozzles from 25mm stand-off distance

Finally, a qualitative and quantitative breakthrough was recorded across all the chamber air conditions and nozzles arrangement after subsequently reducing the number of nozzles to 3 nozzles as shown in **Figure 3.9.**

Where a subsequent alteration of nozzle configurations to 3 nozzles from 4 nozzles significantly increased average amount of scale removed by 86g, 84g and 80g across the respective nozzle arrangements with average removal difference of 17g and 34g between CN and CNO and also the NCN nozzle arrangements. Whereas the 83g average removal recorded in ambient chamber condition was tripled by 218g and 216g as a result of varying the chamber air concentration to compressed and subsequently suction air concentration. The complete sample breakage achieved across board as pictorially demonstrated in **Figure 3.9** was due to the optimum selection of descaling parameters.

## 4. Conclussion

- The amount of scale removed irrespective of it thickness and shape in relation to the hydrodynamic descaling parameter's increases with increase in injection pressure (kinetic energy) and decrease with increase in number of nozzles (header configuration) due to multiple nozzle pressure drops effect.
- While both the selection of nozzles arrangement and chamber air pressure was found to be governed by the shape and size of the scale deposit in question.
- The NCN nozzles arrangement was found to be more efficient in cleaning partially blocked tubing due the absent of center nozzle diverting the jet strength to the side nozzles that are in good contact with the scale deposit. While the introduction of centre nozzles in the CN and CNO arrangement that is in good contact with the surface of the scale target, couple with its ability to aid particle abrasion and lifting capacity of the jet makes the spray jets more suitable for cleaning complete tubing blockage.
- Most importantly, the effect of varying chamber pressure has a direct influence on the spray jet impact because compressing the chamber reduces the kinetic impact of the jet but aide cyclic stress and particle abrasion jetting mechanism. While suctioning the chamber increased the jet impact and also aide hoop stress and cavitation jetting mechanism on the sample.

## Acknowledgement

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## 5. Conflict of Interest

The authors declare no conflict of interest

## References

[1]. K. Y. A. Hassan, "Descaling petroleum production tubing using multiple high-pressure nozzles." University of Salford, 2020.

[2]. S. A. Elmorsey, "Challenge and Successful Application for Scale Removal Gemsa Oil Field, Egypt: Field Study," in SPE Middle East Oil and Gas Show and Conference, 2013.

[3]. E. Hamdy, M. Abu Bakr, A. El-Hay, S. Sisostris, M. Anwar, and O. El Farouk, "Challenge and successful application for scale removal in oil field, Egypt: field study," in International Petroleum

Technology Conference, 2014.

[4]. M. M. Vazirian, T. V. J. Charpentier, M. de Oliveira Penna, and A. Neville, “Surface inorganic scale formation in oil and gas industry: As adhesion and deposition processes,” J. Pet. Sci. Eng., vol. 137, pp. 22–32, 2016.

[5]. Y. A. Alabdulmohsin, I. M. El-zefzafy, M. H. Al-malki, A. A. Al-mulhim, and A. Ali, “SPE-181286-MS Underbalanced Coiled Tubing Mechanical De-Scaling Operations : A Case History for an Oil Well in Ghawar Field from Saudi Arabia,” pp. 1–14, 2016.

[6]. Z. Guimaraes et al., “Efficient Offshore Scale Removal Without a Rig: Planning, Logistics, and Execution,” in SPE/ICoTA Coiled Tubing and Well Intervention Conference and Exhibition, 2008.

[7]. S. A. Ghouri, I. Ali, N. M. Shah, M. Ejaz, and S. A. Haider, “Downhole Scales Management in mature Gas Fields,” Soc. Pet. Eng. - PAPG/SPE Pakistan Sect. Annu. Tech. Conf. Exhib. 2018, PATC 2018, 2018, doi: 10.2118/195659-ms.

[8]. M. Farrokhrouz and M. R. Asef, “Production enhancement via scale removal in nar formation,” in SPE Production and Operations Conference and Exhibition, 2010.

[9]. H. Guan, “Scale deposition control and management in Subsea fields,” in CORROSION 2015, 2015.

[10]. R. E. Esbai and G. Palanisamy, “Eliminating Scale Buildup Challenges and Lessons Learnt from the Fadhili Reservoir Awali Field,” in SPE Middle East Artificial Lift Conference and Exhibition, 2016.

[11]. J. S. Armacanqui et al., “Testing of Environmental Friendly Paraffin Removal Products,” in SPE Latin America and Caribbean Heavy and Extra Heavy Oil Conference, 2016.

[12]. M. Heydrich, A. Hammami, S. Choudhary, M. Mockel, and J. Ratulowski, “Impact of a novel coating on inorganic scale deposit growth and adhesion,” in Offshore Technology Conference, 2019.

[13]. A. Bajammal, F. A., Biyanni, H. M., Riksa, A. P., Poitrenaud, H. M., Mahardhini, “Scale Management in Mature Gas Field: Case Study of Peciko,” in International Petroleum Technology Conference, 2013, doi: doi.org/10.2523/IPTC-16675-MS.

[14]. M. Crabtree, D. Eslinger, P. Fletcher, M. Miller, and A. Johnson, “Fighting scale: removal and prevention,” Oilf. Rev., vol. 11, no. 03, pp. 30–45, 1999.

[15]. A. J. Abbas, G. G. Nasr, M. L. Burby, and A. Nourian, “Entrained Air around a High Pressure Flat Jet Water Spray,” 2013.

[16]. A. J. Abbas, “Descaling of petroleum production tubing utilising aerated high pressure flat fan water sprays.” University of Salford, 2014.

[17]. Palou R. M, Olivares-xomelt & Likhanova N.V (2014) Environmental Corrossion Inhibitors, Development in Corrossion Protection. M .Aliofkharari (ed) InTech, PP, 432-465.http//doi.org/10.5772/57252

[18]. K. Manoj, B. Kumar, and P. K. Padhy, “Characterisation of Metals in Water and Sediments of Subarnarekha River along the Projects’ Sites in Lower Basin, India.,” Univers. J. Environ. Res. Technol., vol. 2, no. 5, 2012.

[19]. Z. Qin, “Investigation of the cavitation mechanism and erosion of submerged high-pressure water jets,” The University of Queensland, 2004.

[20]. A. Haugen, I., Døssland, L., Brankovic, M., Osaland, E., Osugo, L., Grødem, M., & Grønnerød, “Electric-Line Deployed Lightweight Intervention Technology for The Effective Removal of Barium

Sulphate Scale Obstructions from Small Diameter Wellbores," in SPE/ICoTA Coiled Tubing and Well Intervention Conference and Exhibition, 2017, doi: https://doi.org/10.2118/184758-MS.

[21]. K. H. Yar'Adua, I. J. John, A. J. Abbas, K. A. Lawal, and A. Kabir, "An experimental study on high-pressure water jets for paraffin scale removal in partially blocked production tubings," J. Pet. Explor. Prod. Technol., pp. 1–16, 2020.

[22]. G. Chimagwu, G. G. Nasr, and M. Burby, "Characterisation of overlapping flat fan sprays for petroleum applications," in 24th Annual Conference, 2012, pp. 7–10.

[23]. M. A. El Khamki, G. G. Nasr, M. Burby, and A. Nourian, "High pressure overlapping flat sprays nozzles," in 23rd Annual Conference on Liquid Atomization and Spray Systems, 2010, no. September, pp. 1–6.

[24]. M. Qin, D. Y. Ju, and R. Oba, "Improvement on the process capability of water cavitation peening by aeration," Surf. coatings Technol., vol. 200, no. 18–19, pp. 5364–5369, 2006.

[25]. J. N. & Q. X. S. Tian , G. Li , Z. Huang, "Investigation and Application for Multistage Hydrajet-Fracturing with Coiled Tubing," Pet. Sci. Technol., vol. 27, no. 13, pp. 1492–1502, 2009, doi: doi.org/10.1080/10916460802637569.