SPE-207203-MS

Laboratory-Scale Investigation of the Utilisation of Multiple Flat-Fan Nozzles in Descaling Petroleum Production Tubing

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This paper was prepared for presentation at the Nigeria Annual International Conference and Exhibition held in Lagos, Nigeria, 2 - 4 August 2021.

Abstract

Despite the recent wide embrace of mechanical descaling approaches for cleaning scales in petroleum production tubings and similar conduits with the use of high-pressure (HP) water jets, the process is still associated with downhole backpressure and well integrity challenges. While the introduction of sterling beads to replace sand particles in the water recorded high successes in maintaining well completion integrity after scale removal in some recent applications of this technique, it is, unfortunately, still not without questions of environmental degradation. Furthermore, the single nozzle, solids-free, aerated jetting descaling technique – recently published widely – is categorized with low scale surface area of contact, low descaling efficiency and subsequent high descaling rig time. The modifications to mechanical descaling techniques proposed in this work involve the use of three high-pressure flat fan nozzles of varying nozzles arrangements, standoff distances and injection pressures to remove soft scale deposits in oil and gas production tubings and similar circular conduits. This experiment provides further insights into the removal of paraffin scales of various shapes at different descaling conditions of injection pressures, stand-off distances and nozzle arrangements with the use of freshwater. The results obtained from this study also show consistency with findings from earlier works on the same subject.

Key Words: Scale removal, impact pressure, high-pressure water spray, flat-fan nozzle

Introduction

Scale deposition in petroleum production tubing remains a major threat to flow assurance because the production tubing serves as both the main production conduit and a route for well intervention operations (Yaradua et al., 2021) since petroleum products are produced and transported from the reservoir to the surface via pipelines and other flow channels (Nejad & Karimi, 2017) in the reservoir, wellbore and near-wellbore regions, through downhole equipment, wellhead to topside production and processing facilities, pump, separators, heat exchangers, etc. These are all vulnerable to scale deposition, especially when water is present in the flow stream (Guan, 2015). These flow channels most time suffer flow restriction and other damages due to many petroleum production problems including flow restrictions and internal abrasions from scale depositions and transportation of suspended particles (Ghouri et al., 2018). Scale deposition has been said to be a consequence of poor planning and incorporation of scale control strategies (or scale formation prevention) into oilfields asset management planning during the CAPEX phase (Farrokhrouz & Asef, 2010); it is also possible either before the deployment of inhibition or at the expiration of the scale formation inhibitions potency (Smith et al., 2000).

Popular scale deposit types that cause flow restriction are calcium carbonate, calcium and barium sulfates. These and the likes are referred to as inorganic scales (Zahid, 2015). The second classification of scale types (organic scales) includes aliphatic and paraffinic hydrocarbons.

Scale formation has been attributed to the dynamic nature of hydrocarbon production processes and physicochemical changes in the properties of the produced fluids: temperature, volume, pH and pressure. Although other factors like a mixture of incompatible waters, CO_2 liberation, hydrodynamics of the system and flow regime should not be underrated (Heydrich et al., 2019). Organics scale deposition has also been said to be directly connected to the heavy crude production nature of a field. Figure 1 shows the global distribution of heavy crude (Armacanqui et al., 2016) and hence, the likelihood of scale formation in regions of the world.

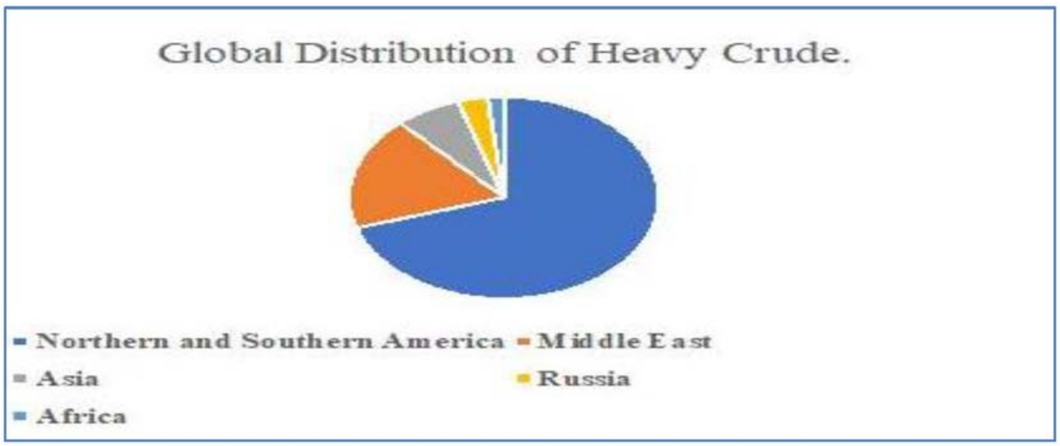


Figure 1—Global Distribution of Heavy Crude (RIGZONE, n.d.)

Tao et al., (2017) characterize paraffin as tasteless and odourless with a melting point ranging from 46 to 68 °C, a density of 900 kg/m^3 and it is insoluble in water but soluble in benzene and some esters.

Many unsafe and non-effective scale removal techniques like the aggressive chemical solutions with HCl (Vazirian et al., 2016) destructive mechanical approaches like the use of mill and cutters (Alabdulmohsin et al., 2016), rig workover to replace the tubing and even differing production has failed to effectively clean production tubings from scale deposits in the past. Although recently, the mechanical high-pressure water jetting techniques have been widely accepted by multinational (Bajammal, Biyanni, Riksa, 2013) it faces back pressure challenges (cavitation). The introduction of the sand particle in the descaling fluid improved scale removal efficiency but, at the expense of the integrity of the well completions (Crabtree et al.1999). Sterling beads replacement of sand resulted in more impressive results of scale removal but also, created concerns of environmental degradation with its usage (Jauregui et al., 2009). While the recent introduction of the single-nozzle, high-pressure, aerated, flat-fan approach was excellent but characterised by poor scale coverage and high rig time (Abbas et al. 2016).

Methodology

This novel experimental scale removal technique utilizes multiple high-pressure flat fan nozzles for a period of 3-minute at a different injection pressure of 4.8 MPa, 6.0 MPa and 10 MPa to clean production tubing from soft scale (paraffin) deposits of different growth stages. Specimens were constructed from household candles as shown in Figure 2. Details of the paraffin wax scale construction and its chemical characterization are provided in (Yar'Adua et al., 2020 and Yar'Adua, 2020).

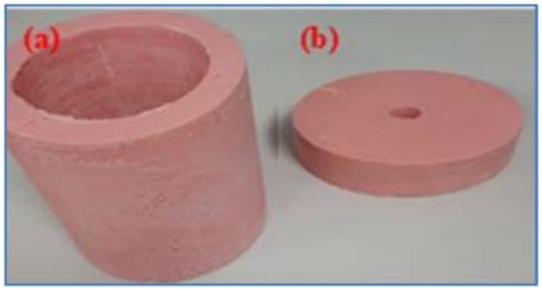


Figure 2—Constructed Soft Scale Sample, (a) Hollow Shape and (b) Solid Shape (Yar'adua, 2020)

The entire experiment was conducted with room temperature water at ambient chamber pressure. All the scale deposits were removed at different injection pressures of 4.8, 6.0 & 10MPa and different downstream distances (25mm, 50mm and 75mm) from the exit orifice of the nozzles to the surface of the scale deposit as shown in Figure 3. The descaling rig schematic shown in Figure 4 comprises a high-pressure water pump and a descaling chamber housing the multiple spray header and the scale deposits (Yar'Adua et al., 2020).

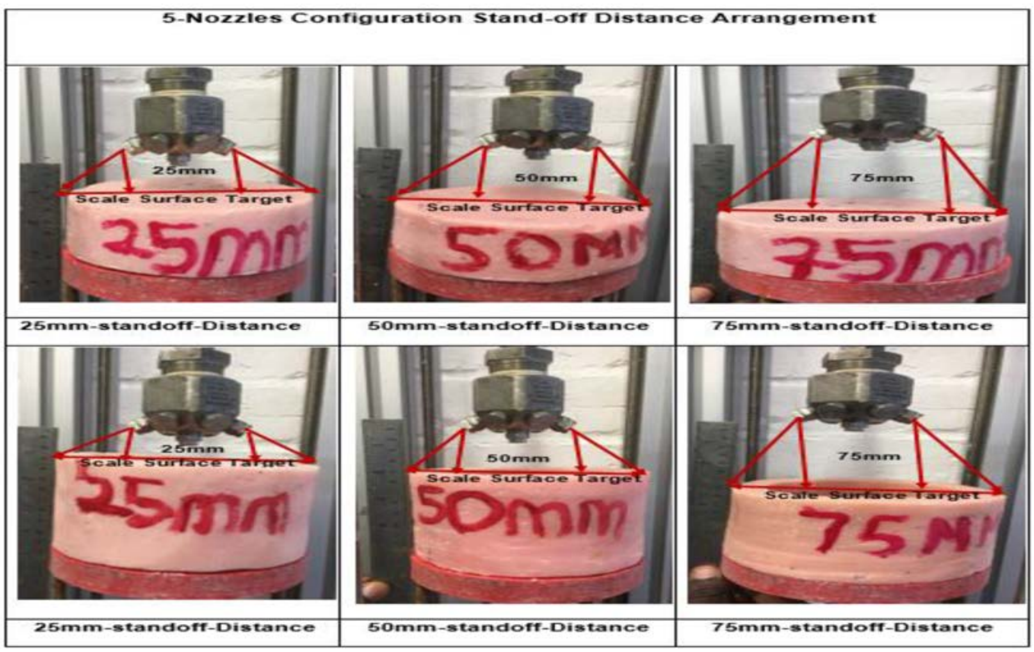


Figure 3—Downstream Distances of Different Nozzle Arrangements (Yar'adua, 2020)

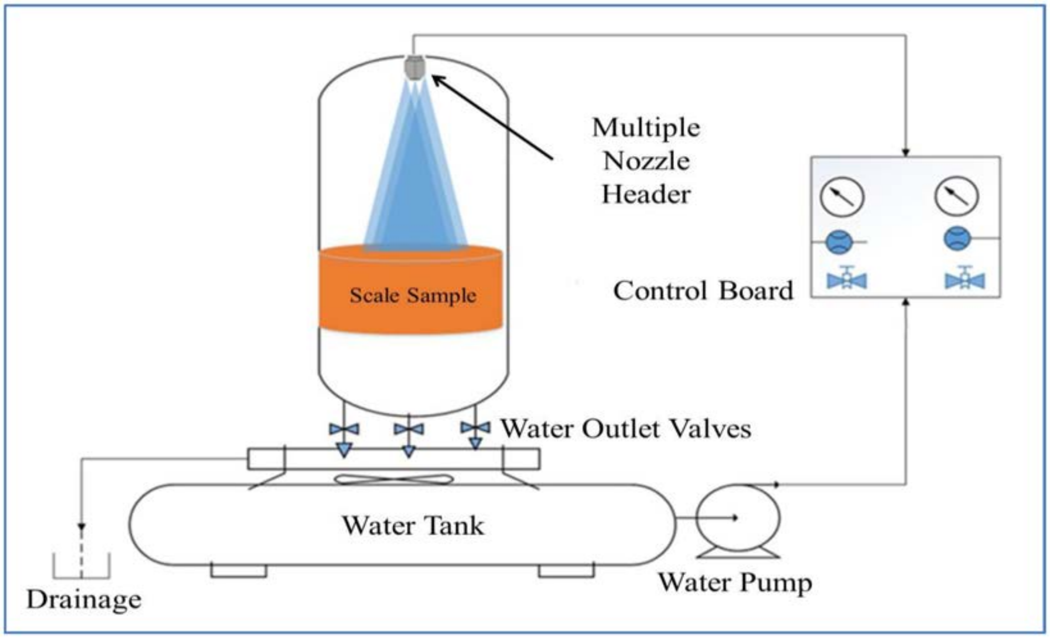


Figure 4—Schematic Diagram of Descaling Setup (Yar'adua, 2020)

Also, the 3-nozzle arrangement was done by fitting the three orifices into 3 of 7 nozzle sockets of the header. The remaining 4 nozzle sockets were blocked with blank plugs as shown in Figure 5 where a triangle, diagonal and right-angle of the non-centre nozzle, centre nozzle and centre nozzle overlap arrangements are shown.

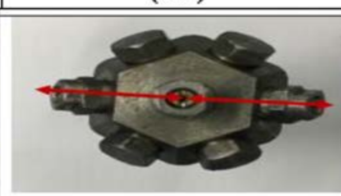
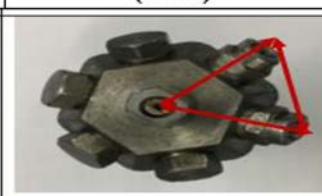
No of Nozzles	Header/Nozzle Configuration		
	Non-Centre Nozzle Configurations (NCN)	Centre Nozzles Configurations (CN)	Centre Nozzle Overlap Configurations (CNO)
3			
	Triangle	Diagonal	Right-angled

Figure 5—Header and nozzles arrangement for 3 nozzles (Yar'adua, 2020)

Results & Discussion

Despite similarities in the chemical properties of the two-scale types studied in this research, their physical differences in shape and size made them respond differently to the different jetting mechanisms (Zongyi, 2004) that resulted when they were exposed to different descaling conditions. The consequence of varying injection pressure that is related to the kinetic energy of the spray was found to be the most important requirement in descaling all the scale types. This is shown mathematically in Equations 1, 2 and 3. Where P_t being the total pressure, P_d is the dynamic pressure or the injection pressure and P_s is the static pressure.

$$Pt = P_S + P_d \tag{1}$$

$$Pd = Ke = \tfrac{1}{2} mV^2 \tag{2}$$

$$v = \sqrt{2Pd / m} \tag{3}$$

Downstream distance adjustment during the experiment demonstrated that decreasing it increases the amount of scale removed irrespective of the scale shape or the injection pressure applied. The case of spraying the samples from a 25mm distance between the side nozzles and scale surfaces yielded the best results. Moving the sample 50mm away from the spray header reduced the jet impact and consequent amount of scale removed, and, further increase of the stand-off distance to 75mm produced a very poor scale removal result for both samples due to poor jet to surface-target impact. This observation is consistent with findings from similar studies on the HP water jets oilfield descaling (Abbas et al., 2013; Abbas 2014; Yar'Adua et al., 2020; Yar'Adua, 2020). However, some experimental runs showed enhanced scale removal efficiency at 50mm and 75mm stan-off distances due to good nozzle arrangement selection.

Nozzles arrangement selection was done taking cognizance of the shape of the descaling samples for better impact and good jet profile since complete target surface coverage is an essential requirement for achieving effective descaling results (El Khamki et al., 2010; Enyi, Nasr, Nourian, 2012). The non-centre nozzles arrangement (NCN) or triangle configuration demonstrated suitability in removing early-stage growth of paraffin deposit in production tubing as a result of the jet impact being diverted to the side nozzles which are in good contact with the paraffin surface. Completely different from that is the centre nozzle arrangement (CN) or diagonal nozzle configuration which proved to be more efficient in removing a complete paraffin production tubing blockage as a result of the introduction of centre nozzles spraying directly on the face of the scale and having more kinetic energy than the sides nozzle and the ability of the centre nozzles to enhance both particle abrasion and particle lifting mechanisms.

The centre nozzle overlaps arrangement (CNO) or the right-angle configuration was also found to be effective in complete tubing blockage remediation. However, it is less effective than the (CN) arrangement due to the complete spray overlap jet profile constraint resulting in a poor jet impact on the target spray samples. In addition to that, the highest droplet velocities concentrated toward the centre of the spray overlap region (Nourian, Amir; Nasr, 2011) that was distrusted. The use of centre nozzles in both CN and CNO arrangements resulted in poor descaling results because for hollow-shaped scales because the centre nozzle jets were not effective as they did not make contact with the progressive scale deposits.

Figure 6 demonstrates the effect of the nozzle arrangement, injection pressure and stand-off distances on scale removal amount for the hollow-shaped paraffin scale samples. The triangle nozzle arrangement of the 3 nozzles at a 25mm distance started by removing 42.8g of the scale deposit. That figure increased to 93.7g and further skyrocketed to 253.8g as a result of increasing the injection pressure by 1.2MPa and by a further 4.0MPa respectively (Figure 6A). Similar trends were observed in Figure 6B (the diagonal arrangement) and Figure 6C (the right-angle nozzle arrangements). In the latter, for instance, the initial 32.7g of displaced scales weight increased by 52.9g at 6MPa injection pressure and went as high as 180g at 10MPa injection pressure.

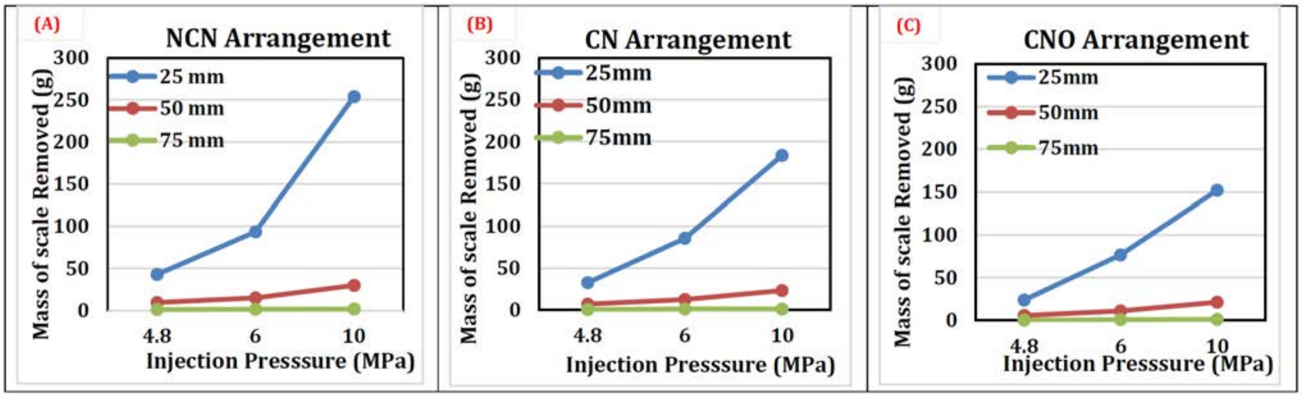


Figure 6—Descaling result of hollow shaped paraffin sample at different descaling parameters

The significance of the spray injection pressure on the amount of scale removed tends to be more pronounced at 25mm stand-off distances than higher values of 50mm and 75mm. Nonetheless, for all three nozzle configurations, more scales were displaced with increasing spray injection pressure. Figure 6 also shows that higher scale values were removed at lower stand-off distances for all combinations of nozzle arrangements and spray injection pressure. Specifically, a difference of 223g & 28g, 161g and 22g, 131g and 20g were recorded after increasing the downstream jetting position from 25mm to 50mm and later 75mm, respectively, for the NCN, CN and CNO nozzles arrangements, all at 10MPa spray injection pressure.

If we consider the lowest stand-off distance of 25mm across all three nozzle configurations, the significance of varying the arrangement of the nozzles becomes evident: reductions of 10.1g, 8.1g and 70.1g were recorded in the amount of hollow scales displaced at 4.8MPa, 6.0MPa and 10MPa injection pressures respectively after altering the nozzle arrangement from triangle (NCN) to diagonal (CN). When the nozzle arrangements were later changed to the right-angle configurations these discrepancies were 18.8g, 16.7g and 101g respectively (Figure 6).

Figure 7 elaborates the effects of injection pressure, nozzle arrangement and stand-off distance during the "solid shape" paraffin samples removal experiment. Trends similar to those observed for hollow scales were seen but with less severity due to the differences in the thicknesses of the samples. The triangle nozzle arrangement initially removed 4.1g of paraffin at a 25mm distance. This increased slightly by 1.3g and then, skyrocketed by 57.7g due to injection pressure alteration by 1.2MPa and later 4MPa, respectively (Figure 7a). While both diagonal and right-angle nozzle arrangement improved their initial removals of 5.2g & 4.7g, respectively by 2.1g after throttling up the injection pressure by 1.2MP. These both rose by 96g & 74g due to an additional 4MPa injection pressure increase (Figure 7b and 7c).

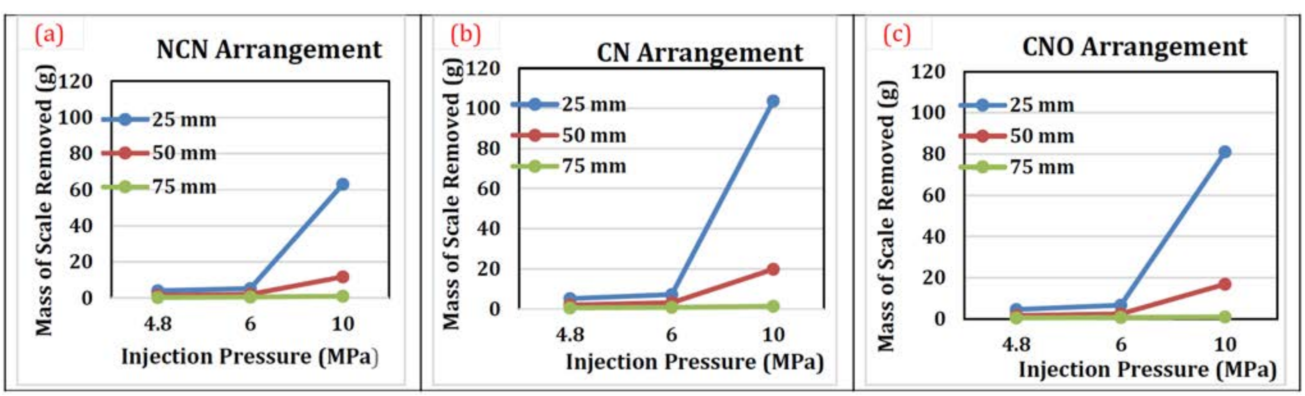


Figure 7—Descaling result of solid shaped paraffin sample at different descaling parameters

The effects stand-off distances were more conspicuous at the 25mm stand-off distance values and 10MPa injection pressure experimental trials. This can be attributed to the fact that this scenario enhanced the jet impact pressure, mass flow rate of the jetting fluid and, where the nozzle configuration is effective, the surface area of contact of the jetting fluid on the scale sample.

The 63g initial amount of paraffin removed with triangle arrangement at 25mm reduced by 51g and later, by 11g after increasing the jetting position to 50mm and 75mm respectively. A similar trend was observed with both diagonal and right-angle arrangement respectively were their initial 25mm removal at 10MPa of 104g & 81.1g was reduced by 84g & 65g and later by 17g & 14g after subsequently increasing the jetting position to 50mm and 75mm respectively.

The diagonal nozzle arrangement was found to be more effective in removing solid shape paraffin. The next-most-effective is the right-angle configuration and the lease of them is the triangle due to the centre nozzle effect earlier discussed. The diagonal arrangement at 25mm distance across the respective injection pressure removed 5.2g, 7.3g and 104g of paraffin that reduces by 0.5g, 0.5g & 23g with the right-angle arrangement and further by 1.1g, 1.9g & 41g with the triangle nozzle arrangement respectively.

Conclusion

The experimental results show that the amount of scale removed increased with an increase in the descaling fluid injection rate and a reduction in the downstream distance. This result is consistent with previous findings on the subject. In addition to that, this study proves that the negative effect of increased downstream distance (or stand-off distance) on the scale removal efficiency can be ameliorated with the right choice of nozzle arrangements.

Acknowledgements

This research would not have been possible without the technical and financial support of the Spray Research group of the University of Salford, Manchester and the Petroleum Trust Development Fund (PTDF) of the Federal Government of Nigeria.

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