# Removal of Scales in Petroleum Production Tubing Utilising High Pressure Atomisers

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## Abstract

Scale is a mineral deposit usually formed on surfaces in contact with water. Scale deposition in petroleum production wells can be attributed to mixing of incompatible waters, changes in thermodynamic, kinetic and hydrodynamic conditions in oilfield operations.

Scale creates serious problems in producing, injection and waste disposal wells. It may restrict and completely plug off production in the formation, tubing or in flow lines. Scale prevention using chemical and mechanical methods are limited in application and depend on the type of well completion method used. This investigation proposes a new technique to address the problem and lay the foundations for a methodology for descaling in-situ production in oil and gas wells. The technique uses flat fan atomiser to produce high water pressure of 6 MPa, flow rate of 23 l/min and high impact force of 0.657 MPa which are used to dislodge scales build-up along the production tubing. Simulated laboratory scale removal rig was designed and built to demonstrate the effects of using overlapping flat fan spray atomisers to remove scales that were formed in oil and gas production tubing. This non-destructive method provides significant advantages over current scale removal methods that involve the use of chemicals or other harmful substances which are impediments to the environment and can also affect the integrity of the pipe.

Three scale samples from oil and gas wells from North Africa and one laboratory prepared candle wax scale were tested using single flat fan atomiser and a combination of two and three high pressure and high impact force atomisers. The Volume of Scale Removed (VSR) was measured experimentally using a combination of atomisers, at different spray angles, downstream distances, and water supply pressures and spraying times. The maximum quantity of scale removed using the soft candle wax was found to be 53 $cm^3$ at spray cone angle of 30 degree at 75 mm downstream distance from the atomisers exit. Moreover, the volume of scale removed from other three samples was found to be 11.688 $cm^3$ for the soft gas scale, 13.750 $cm^3$ for the oil wax scale and approximately 0.989 $cm^3$ for hard scale sample at 75 mm downstream distance.

KEYWORDS: Scale removal, Flat-Fan atomiser, Overlapping spray

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## Introduction

One of the major problems facing the oil and gas industry is that of the mineral growth forming in hydrocarbon producing wellbore. Scale is a mineral deposit usually formed on surfaces in contact with water. Some common scales associated with oil field brines are calcium sulphate, barium sulphate and calcium carbonate. Scale deposition can be attributed to such factors as pressure drops, mixture of incompatible waters, changes in physical or chemical environment, or temperature changes that the well fluids encounter [1, 2].

The primary effect of mineral growth in the tubing is to lower production rate by increasing the surface roughness of the pipe and reducing the flowing area. The pressure therefore increases and production decreases. If the mineral growth increases, the access to lower sections of the well becomes impossible and ultimately the growth in the tubing itself will block completely [3, 4].

Treatment of scale down the tubing-casing annulus protects down-hole equipment but may not be effective at the face of the formation.

There are two conventional methods for removing these oilfield scales. The first is the chemical method which involves adding chemical agents to the produced fluids to prevent the formation of solids or to prevent the solids that are formed from sticking to the surfaces of pipe or equipment. In many cases, however, it is not possible to apply this method because of the way the oil or gas well was completed. In such cases, the down-hole scale can sometimes be removed after it is formed by dissolving it with a strong acid solution. This method is not always successful because some forms of scale do not easily dissolve in acid [4]. The second is the mechanical method which uses milling tools. This method often leads to damage of the tubing. Scale deposition costs the petroleum companies over $1,000,000 each year [5]. Hence there is the need to develop a new technique for scale removal in the petroleum production tubing without damaging the integrity of the tubing.

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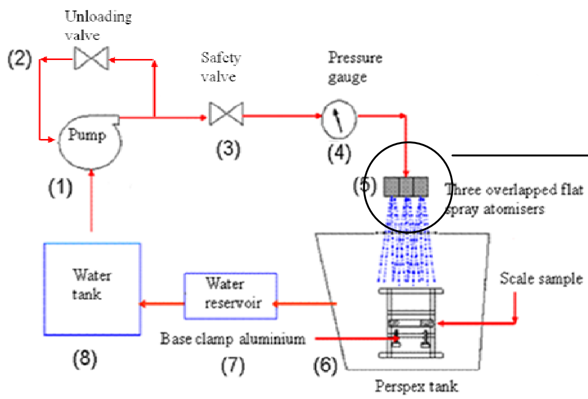
High pressure water sprays technique was tested for this purpose. In order to test the spray technique operating under ambient condition; an experimental test facility was initially built in the Spray Research Group (SRG) laboratory at the University of Salford, UK.

## Experimental Apparatus and Assembly



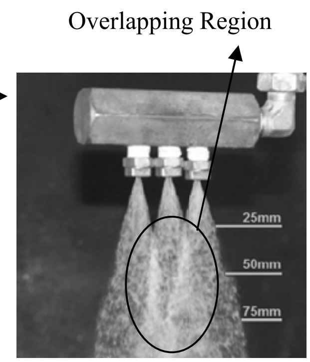




**Figure 1a** Liquid spraying atomisers and holding block **Figure 1b** Dense overlapping region

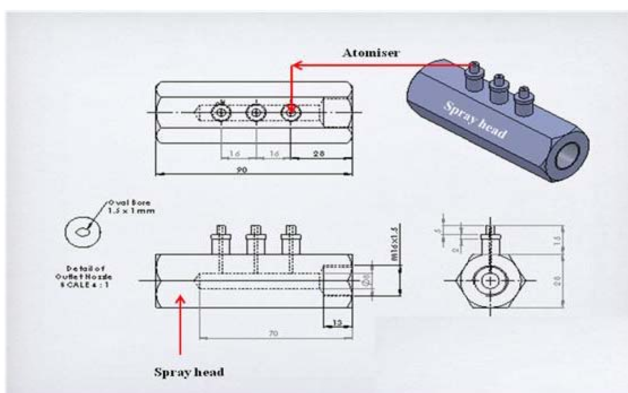



**Figure 2** Sketch of the nozzle system

The schematic arrangement shown in Figure 1a was designed to experimentally demonstrate oilfield scale removal through the use of flat fan atomizers to generate overlapping sprays from high pressure water. It consists of a pump (1), unloading valve (2), safety valve (3), gauge pressure (4), three atomisers spray head (5), tubing sample (6), water reservoir (7), and water tank (8). The Speck Kolben pump (1) delivers high pressure water of about 6 MPa and flow rate of 23 l/min to the "Spray Head" shown in Figure 2. The purpose of this pump was to increase the pressure of the water to guarantee the desired high impact force which is necessary to remove the scale. The water pressure is regulated through the pressure gauge (4) to the spray head. A pressure relieve valve (3) was provided within the pump circulation loop to protect the entire assembly from excessive pressure. As a further safety measure, an un-loader valve (2) was installed within the pump as a regulator when the water pressure reaches the adjustment limit. Three pieces of Perspex tube were fixed together by means of flanges and aluminium bars. The top Perspex tube contains the scale sample tubular with the middle one carrying the sieves. The bottom tube fixed below the bench returns the water to the reservoir tank. The water tank is made of High Density Polyethylene (HDPE). This HDPE material is anti-rust making it the best choice for the experimental work because of non-interference with the results. It was fitted with an outlet valve which was connected to the pump inlet line, and an outlet valve for the return of water to the pump thus maintaining a steady and continuous flow.

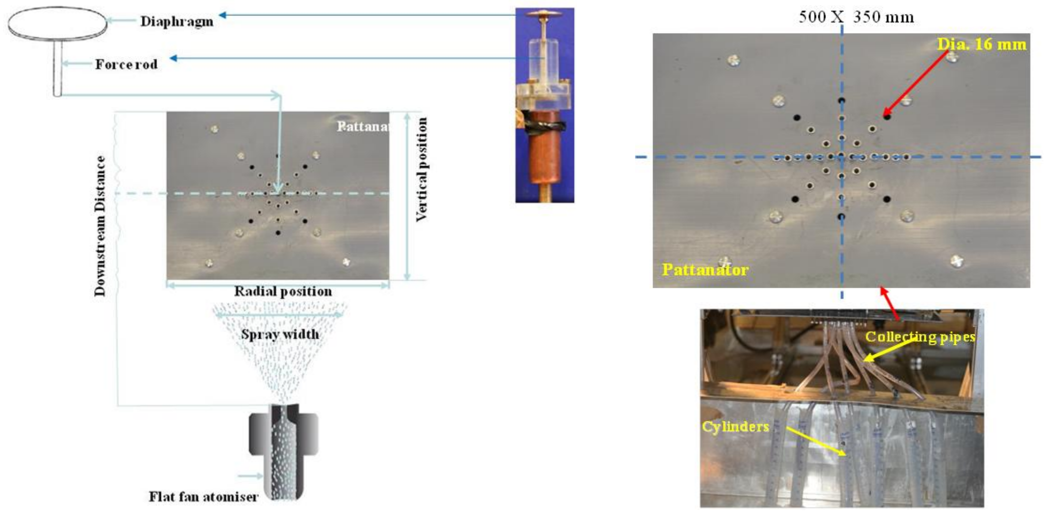



**Figure 3** Schematic setup for Volume flux and Impact force measurements

The spray head assembly shown in Figure 2 is one of the vital part/component of the scale removal apparatus because it has a direct interaction with the scale sample. It consists of brass hexagonal bar machined to accommodate 3-atomisers spray at equidistant to one another from the centre axis. The distance between the three single nozzles was chosen after several trials based on the cone angle and the distance that gave the best overlapping effects. Flat fan spray atomiser was used in this research to provide the necessary water spraying stream to remove the corresponding scales easily.

The aluminium clamp was fixed to the base of the Perspex tank and was pushed downwards to provide suction between the rubber seating and the bottom of the rectangular Perspex box. This arrangement allowed the scale sample to be rigidly clamped to the base of the tank thus preventing it from any form of movement during the entire period of descaling.

The sieve was place on top of the tank under the transparent rectangular Perspex box to collect scale removed from the sample during spraying operations. The mesh size employed for the collection of the removed scale has an aperture of (180µm). It is made of stainless steel which conforms to BS410-2:200 British Standard Institution specifications.

**Experimental Procedures for Impact Force and Volume Scale Removal Measurements**

***Spray Impact Force Measurement***

The spray impact force at the wall of the oil tubing is a very important parameter for scale removal, as it relates directly to the force required for removing the scale deposit, and this depends upon the hardness of the scale. It is also important that the impact force of the spray is less than that which would cause damage to the oil tube wall.

The impact force was measured across the spray using a patternator. The technique adopted for removal of hard scales from inner surfaces of the well tubular in oil and gas well relies heavly on the use of high pressure water atomisers with high impact force [6,7,8]. Figure 3 shows schematically the arrangement to determine the impact force and volume flux for one atomiser and a combination of two and three overlapping flat fan spray atomisers.

The patternator was adjusted so that the required position of the spray should be impacting upon on the diaphragm. A sensor was mounted in chosen location on the patternator and a deflector plate was placed on the patternator before applying water pressure onto it. Water at a pressure of 6 MPa and flow rate of 23 l/min was directed to the flat fan atomisers along the desired downstream position of 25, 50 and 75 mm. A stop watch was started and the water deflector was then removed to allow the high pressure water to impact upon the diaphragm/transducer. At the end of 20 seconds, the water was shut and the volume of water collected in the receptacles (collecting pipes and cylinder) was recorded.

***Volume Scale Removal Measurement***

The volume scale removal trials used the actual oilfield soft and hard scales samples, as well as a laboratory made soft scale using a candle wax as a means of comparison with the results obtained from the actual oilfields scale samples. The scale samples from Sirte Oil Company, in Libya shown in Figure 4 and wax scales prepared from our research laboratory were used in this investigation.

The scale samples were placed on the aluminium base flange and secured in position. The spray head is lowered vertically downwards to carefully select a predetermined height to coincide with the radial axis of each sample; thus ensuring that the spray impact the scale at the correct angle, at the right target, at different pressure, flow rate, height and precise timing respectively.

| No | Scale Type | Scale sample Image |
|---|---|---|
| 1 | Candle Wax Scale Sample (CWSS) |  |
| 2 | Wax Oil Scale Sample (WOSS) *From Libya* |  |
| 3 | Soft Gas Scale Sample (SGSS) *From Libya* |  |
| 4 | Hard Oil Scale Sample (HOSS) *From Libya* |  |

**Figure 4** Types of scale samples

The water pump was switched on to start the descaling operations at an initial water flow rate of 8 l/min. and pressure of 3.7 MPa, and then adjusts to obtain the desired flow rate and pressure of 23 l/min and 6 MPa respectively for three overlapping flat fan atomisers. The overlapping spray jets from the atomisers were directed axially to the scale sample to be removed as shown in Figure 5. The experiment was performed on totally plugged pipe, hence the jet was directed axially on the scale. For partially plugged pipes as shown in Figure 4, the jet will impinge tangentially on the scale.

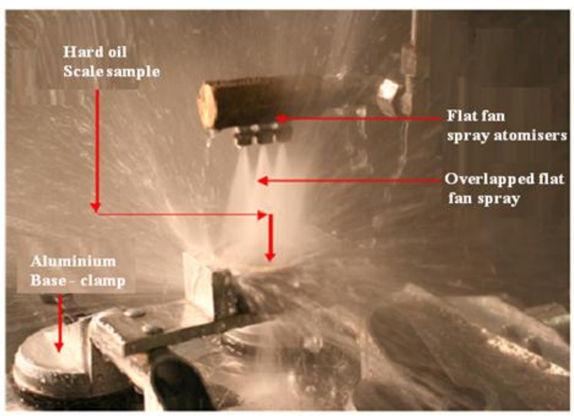



**Figure 5** Snap-shot of descaling operation using three atomisers


**Figure 6a** Soft Scale Sample

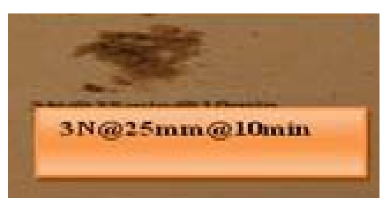



**Figure 6b** Hard Scale Sample

After 15 minutes of spray operation, the water pump was switched off and the scale particles collected by the sieve were dried and weighed with a weighing scale. The procedure above was repeated for desired pressure of 4.8 MPa and at desired flow rate of 14 l/min using two overlapping flat fan spray atomisers for 10 and 15 minutes.

The snap-shot of scale samples removed from soft and hard scales samples using three nozzles (3N) placed at downstream position of 25 mm and after 10 minutes (3N@25mm@10min) of operation are shown in Figures 6a and 6b respectively while Tables 1 and 2 show the volume of soft and hard scales removed at different downstream distances and spray time using three overlapping flat fan atomisers.

**Table 1** Typical tabulated results of VSR using Soft Gas Scale Sample (SGSS) for three atomisers

| **Pressure (MPa) ($1x10^{-3}$)** | **Flow rate (l/min)** | **Spray-ing Time (min)** | **Down-stream Distance (mm)** | **Initial weight of sample (g)** | **Final weight of sam-ple (g)** | **Scale re-moved (initial weight-timeout weight (g)** | **Vol. of scale re-moved ($cm^3$)** | **Remarks** |
|---|---|---|---|---|---|---|---|---|
| 6 | 23 | 5 | 25 | 565 | 563.75 | 1.25 | 1.560 | Scale Removed |
| 6 | 23 | 10 | 25 | 565 | 563.28 | 1.72 | 2.150 | Scale Removed |
| 6 | 23 | 15 | 25 | 565 | 563.26 | 1.74 | 2.175 | Scale Removed |
| 6 | 23 | 5 | 50 | 565 | 562.58 | 2.42 | 3.025 | Scale Removed |
| 6 | 23 | 10 | 50 | 565 | 561.51 | 3.49 | 4.363 | Scale Removed |
| 6 | 23 | 15 | 50 | 565 | 561.48 | 3.52 | 4.400 | Scale Removed |
| 6 | 23 | 5 | 75 | 565 | 559.98 | 5.02 | 6.275 | Scale Removed |
| 6 | 23 | 10 | 75 | 565 | 557.80 | 7.20 | 9.000 | Scale Removed |
| 6 | 23 | 15 | 75 | 565 | 555.65 | 9.35 | 11.688 | Scale Removed |

**Table 2** Typical tabulated results of VSR using Hard Oil Scale Sample (HOSS) for three atomisers

| **Pressure (MPa) ($1x10^{-3}$)** | **Flow rate (l/min)** | **Spray-ing Time (min)** | **Down-stream Distance (mm)** | **Initial weight of sam-ple (g)** | **Final weight of sam-ple (g)** | **Scale removed (initial weight-timeout weight (g)** | **Vol. of scale re-moved ($cm^3$)** | **Remarks** |
|---|---|---|---|---|---|---|---|---|
| 6 | 23 | 5 | 25 | 620 | 619.94 | 0.060 | 0.021 | Scale Removed |
| 6 | 23 | 10 | 25 | 620 | 619.00 | 0.100 | 0.036 | Scale Removed |
| 6 | 23 | 15 | 25 | 620 | 619.88 | 0.120 | 0.042 | Scale Removed |
| 6 | 23 | 5 | 50 | 620 | 619.85 | 0.125 | 0.053 | Scale Removed |
| 6 | 23 | 10 | 50 | 620 | 619.81 | 0.190 | 0.067 | Scale Removed |
| 6 | 23 | 15 | 50 | 620 | 619.79 | 0.210 | 0.074 | Scale Removed |
| 6 | 23 | 5 | 75 | 620 | 619.75 | 0.250 | 0.088 | Scale Removed |
| 6 | 23 | 10 | 75 | 620 | 618.23 | 1.770 | 0.625 | Scale Removed |
| 6 | 23 | 15 | 75 | 620 | 617.20 | 2.800 | 0.989 | Scale Removed |

## Results and Discussions

Experimental tests were performed for one, two, and three atomizers at different downstream distances, flow rates and spraying time. Here, most of the results discussed centred on three overlapping flat fan atomisers arrangements at a pressure of 6 MPa and flow rate of 23 l/min though mention were made of one and two atomisers for comparisons.

***Spray Impact Force***

The analysis of Volume Scale Removal (VSR) results obtained in the various experiments are presented and discussed, using the data collected from various scale samples. The amounts of scale removed were measured when using the single atomiser, as well as the two and three atomizers.

The distance between the orifice of the atomiser and the targeted sample surface (downstream distance) was maintained at (25, 50 and 75 mm). The cross section of the force sensor was maintained constant for all the distances however the total force acting on the whole nozzle was not investigated in this experiment . The spray should have sufficient impact force to shear the scale with adequate contact on the scale sample. The VSR results generally show that increasing the downstream distance together with an increase in atomiser numbers, substantially increases the volume of scale removed from the sample.

Figure 7 shows the results of the impact force ($I_F$) of one, two and three overlapping atomisers at the centreline of the spray at various downstream distances (25, 50 and 75 mm). The results show that for a given downstream position, the number of atomisers and increase in water pressure increases the impact force and the volume of scale removed.

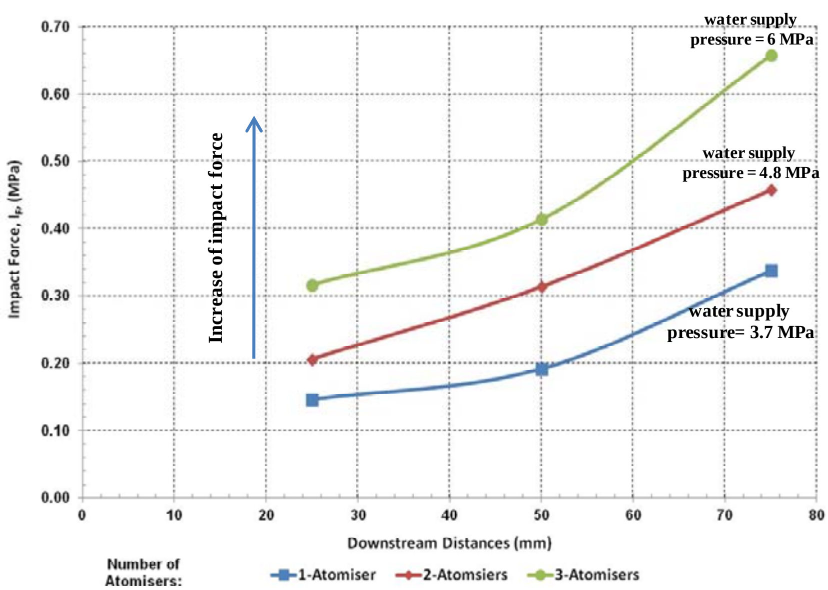



**Figure 7** Impact force one, two and three atomisers at the spray centreline

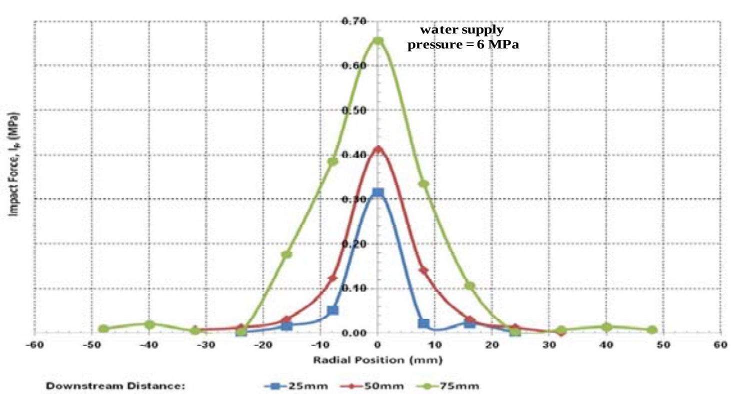



**Figure 8** Impact force at various locations across the spray for *three atomisers* using patternator.

Figure 8 shows the results of impact force at different downstream distances 25, 50 and 75 mm for three atomisers' combination. It can be seen that the range of impact force lies between 0.32 MPa to 0.657 MPa. It was found that at a water supply pressure of a (≥ 6 MPa); the removal of hard scale appeared to be significant. The water pressure and the impact force required to shear the scale was found to be substantially less than those obtained during each trial on the test sample. The force profiles in Figure 8 have Gaussian shape, it is expected that some kind of force plateau should form around the centre line. Future work is ongoing in this area.

Therefore this technique, that was adopted for removal of hard scales from inner surfaces of well tubular in oil and gas well relies heavily on the use of high pressure water atomiser with high impact forces, that is capable of producing coarse volume median diameter (D0.5) dropsize of between 200 μm to 350 μm.

***Volume Scale Removed (VSR)***

Scale removal tests were carried out on oil scale samples using one, two and three atomisers at three different downstream distances of 25, 50 and 75 mm. Tables 1 and 2 show typified results of VSR for SGSS and HOSS trials for three overlapping flat fan atomisers. Figure 9 represents the volume of soft gas scale sample removed by using a combination of three flat fan spray atomisers at different downstream distances. The maximum volume of scales sheared off from the sample surface at 75 mm downstream, spray cone angle of 30 degree and at spraying time of 15 minutes was 11.688 $cm^3$. Applying the same experimental conditions on oil wax scale, a total volume of 13.750 cm3 was removed while for hard scale samples as shown in Figure 10, the volume of scale removed was approximately 0.989 $cm^3$.

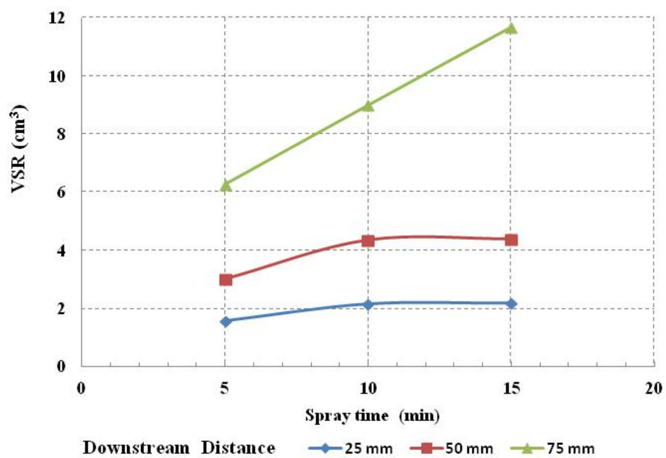



Figure 9 Scale removals of Soft Gas Scale Sample (SGSS)

It is interesting to note that with the application of one atomiser to three atomisers, there is a steady increase in the volume of scale removed, whereas for the three atomisers overlapping combinations, there is a significant increase in VSR compared with one or two atomisers' applications. This confirms the dependency of VSR on spraying at high water supply pressure (≤ 6 MPa) with high impact force (≤ 0.657 MPa) and with overlapping configurations. As can be seen from Figure 10, the most effective way of removing scale appeared to be with three atomisers combinations particularly for downstream of the exit orifice. At 75 mm downstream, there are regions of highly dense overlapping sprays as shown in Figure 1b which was due to high applied pressure which could provide substantial impact force in breaking up the hard oil scale.

## Conclusions

It can be concluded that the impact force increases with both the pressure and the number of atomisers for different downstream positions. For a pressure of 4.8 MPa and with two atomisers at downstream positions of 25, 50 and 75 mm, the impact force ($I_F$) was found to be approximately 0.206 MPa, 0.313 MPa and 0.457 MPa while with three atomisers, it was found to be 0.316 MPa, 0.413 MPa and 0.657 MPa at supply water pressure of 6 MPa and flow rate of 23 l/min.

From the results, it is evident that removing various volume of scales depends on the selection of atomiser type (i.e. flat fan spray), number of atomisers, spray distance and time, supply water pressure and impact force of the spray.

It should be noted that all trials in this investigation were conducted under ambient condition, at water pressure of 3.7, 4.8 and 6MPa, flow rate of 8.0, 14.0 and 23 l/min and impact force of ≤ 0.657 MPa for one, two and three atomiser configurations respectively. Further investigations using simulated pressure vessel (≤ 20 MPa) to remove the deposited scale under realistic condition as well as the gradual increase of supply water pressure are ongoing. The results and analysis presented here, from the current research, have provided an in depth knowledge data base which will greatly assist future investigators into this important and problematic area that currently exist in the petroleum industry.

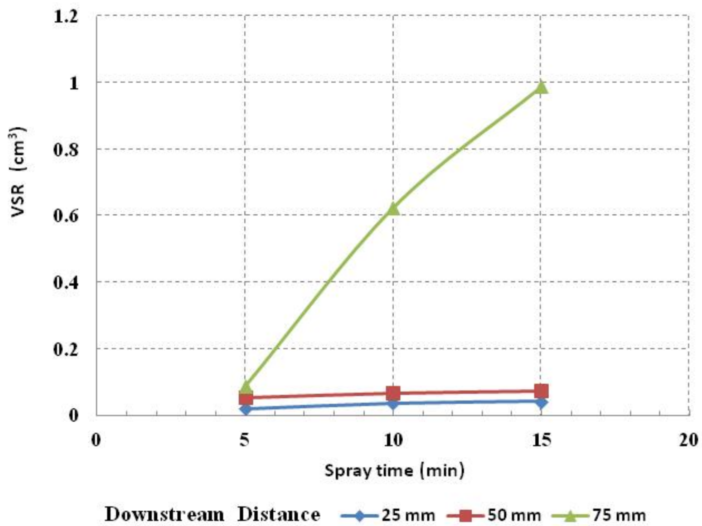



**Figure 10** Scale removals of Hard Oil Scale Sample (HOSS)

## Acknowledgements

The lead author acknowledges the financial and technical supports of the Spray Research Group (SRG) and Petroleum and Gas Engineering Division at the University of Salford, UK.

## References

[1] American Petroleum Institute, *Introduction to Oil and Gas Production*, Production Dept, API, Dallas Texas 1983.

[2] American Petroleum Institute, *Subsurface Salt Water Injection and Disposal*, Production Dept, API, Dallas Texas 1983.

[3] Cabtree, M., Eslinger, D., Fletcher, P., Johnson, A., and King, G., *Scale – Removal and Prevention,* Oil Review, Autumn, 1999.

[4] Cenegy, L. M., McAfee, C. A., and Kalfayan, L. J., *Field Study of the Physical and Chemical Factors Affecting Downhole Scale Deposition in the North Dakota Bakken Formation* SPE 140977 presented at the SPE International Symposium on Oilfield Chemistry, The Woodlands, Texas, April 11 – 13, 2011.

[5] El-Kamkhi, M.A., Nasr, G.G., Burby, M., and Onyukwu, E., *The Characterization of Overlapping Flat Sprays for Descaling Oil and Gas wells,* 11th Triennial International Conference on Liquid Atomization and Spray Systems, Vail, Colorado, USA, 2009.

[6] Yule, A. J., and Widger, I. R., *Swirl Atomizers Operating at High Water Pressure*, Int. Journal of Mechani cal Science 38, Nos 8 -9, 981 – 999, 1996.

[7] Nasr, G. G., Yule, A. J., and Lloyd, S. E., *The Characterisation of the Spray from a New Fine Spray Spill Return Swirl Atomiser* Proceedings of the 21st ILASS – Europe Meeting, 2007.

[8] Nasr, G.G., Yule, A. J. and Bendig, L., *Industrial sprays and atomisation; design, analysis, and application*, 1st Edition, Springer Verlag, London, 2002.