SCALE REMOVAL FROM DOWN-HOLE TUBING OF OIL AND GAS, UTILISING HIGH PRESSURE WATER ATOMISERS: a review, design simulation and analysis

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ABSTRACT

This is an investigation of the novel utilization of high pressure water sprays impacting upon surfaces of the down-hole tubing of oil and gas wells in order to remove scale. A combined experimental and modelling/theoretical investigation is planned with cooperation between the University of Nottingham and the University of Salford.

The experimental work will have two aspects: scale removal experiments of simulated down-hole tubes under atmospheric pressure conditions, to concentrate on fundamental aspects of the problem, and scale removal of the simulated down-hole tubes at high ambient pressure (typically 20MPa) to more closely match practical conditions. Theoretical/modelling work will be based upon existing codes with the addition of sub-models for water spray-scale removal under different oil and gas well operating conditions.

This paper provides a detail review of the past and current work involved in removing the hard scale from the production tube of the oil and gas wells. It will also give an overview of the design and analysis of the proposed simulated apparatus under atmospheric pressure conditions, using high pressure water atomisers, which will be used in determining the removal of the corresponding scale.

THE PROBLEM

Fluid (typically seawater) is currently injected into petroleum reservoirs for "pressure maintenance" when the rate of oil/gas production is declining due to low reservoir pressure (typically 20MPa). Scaling constituents in the water and sometimes from the reservoir rock can build up in oil well tubing perforations or in the completion string, either reducing the flow area or inducing failure of completion components like gas-lift valves or sub-sea safety valves. The scales are typically Barium Sulphate, Strontium Sulphate, Calcium Sulphate, Calcium Carbonate and radioactive materials such as Radium-226 (Ra-226) and Radium-228 (Radium-228). These scales are difficult to remove from down-hole well tubing using mechanical, chemical or biological methods, because they are hard and chemically stable.

This investigation will develop knowledge and guidelines for removal of hard scale from the inner surfaces of down-hole production tubing by utilizing water sprays with high impact forces. A specially developed apparatus will provide the main information. Inter-disciplinary aspects include the transfer of knowledge from descaling technologies [1-5] in the steel industry and the use of atomic force microscopy to quantify adhesive forces for different scale conditions.

The research will be carried out in cooperation with leading oil/gas companies. The high-pressure water spray technique is a convenient method to assemble and operate, which will greatly reduce the capital and operating costs of the plant compared to other methods such as abrasive jetting, jet blaster techniques or mechanical methods (mills, bits, sonic hammer, impact hammer, reamers etc.). The new proposed method in this investigation intends to restore 100% of production loss due to scale formation.

PAST AND PRESENT WORK

Figure 1 illustrates a typical well. When a new well is drilled, gas/oil/water flows naturally since the reservoir is fresh and the pressure is substantial (i.e. 20MPa). After 10 to 20 years the reservoir pressure declines and is insufficient to lift the production to the surface. The usual "artificial lift" methods are Gas Lift (GL) and Electrical Submersible Pump (ESP). In the former gas is injected via a series of gas lift valves into the production tubing (Figure 1).

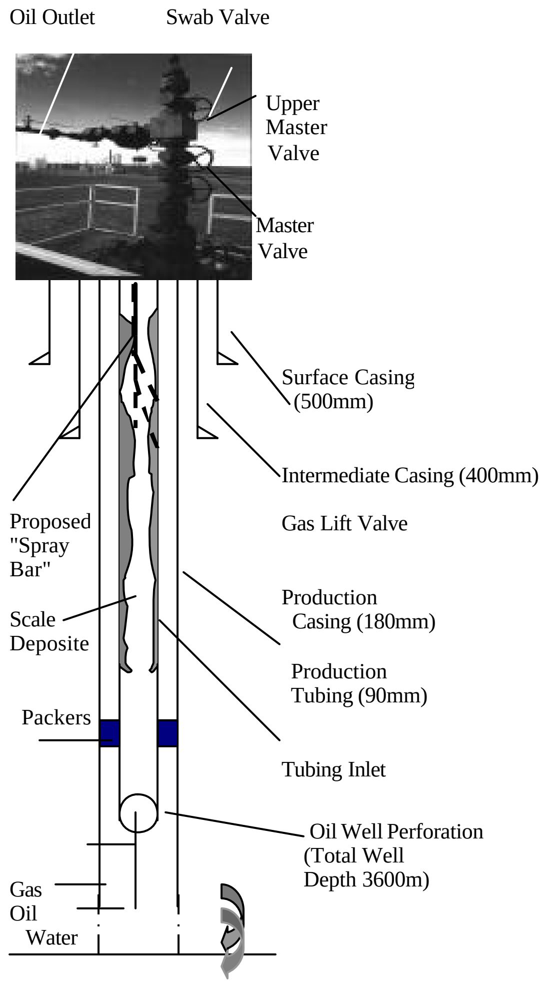

Figure 1 Schematic illustration of a typical well with its dimensions

This reduces the density of the oil and enables free flow of the products onto the surface. In the ESP method a pump is fitted inside the production tubing casing to lift the oil to the surface. These processes are highly dependent on the inner surface of the production tube casing being free of scale formation, thus providing smooth flow to the surface and, at the same time, increasing the production rate. In addition a "pressure maintenance" process may be used to keep the reservoir pressure at, say, 20MPa. The “oil displacement” process also displaces the oil to the main well production via a "well boundary" located in the vicinity of the main well. Both of these processes involve injection of fresh water or seawater, depending on the well location. Furthermore, during the shut down maintenance process, salt water (brine), having a higher density than water, is also injected into the well to overcome the increase in pressure in the production tubing. The excess water, resulting from this process, is sucked back to the surface. In all these processes, pressure maintainace, oil displacement, shut down maintenance, when aquifer drive is maintained by injecting surface water; it increases the chances of scale formation, particularly in the production tubing.

As the well production declines water production normally increases and the potential of scale precipitation increases. Scale can build up in the perforations or in the completion string, either reducing the flow area completely or partially plugged the production tubing as typified in Figure 1. This may also induce failure of completion components like gas-lift valves or sub-surface safety valves. The worst scenario is that production tubing must be removed and perforated to increase production and extend well life.

Mackay et al [6] noted that fluid temperature (using fresh water mixed with seawater) may have significant impact on thermal fracturing of scale in the production tubing. It is planned in the second phase of this investigation to study systematically the influence of water temperature (<100 ^{o}C) on removing the scale.

There are currently different methods that are used in petroleum in removal of scale from the production tubing. These are: *(i) mechanical method, (ii) chemical injection and squeeze methods, and (iii) abrasive jetting method (or fluid mechanical method)*. However, every one of these methods is subjected to degradation of tubing. The corresponding scales have limited solubility, and thick deposits are very often difficult to remove by those conventional methods. The use of dissolvers to remove scale is not only frequently unsuccessful but can also be environmentally unfriendly. Barium Sulphate does not dissolve in acid unless it is converted into acid soluble. The conversion process is very expensive and time consuming, and the converter works only on the scale surface area that it contacts. Mechanical methods (mills, bits, sonic hammers, impact hammers, reamers etc) are also very expensive and time consuming when dealing with extremely hard scales. Recently, for example, Schlumberger Ltd. [7] applied a pressurised mechanical bits method in an attempt to remove the scale in the oil and gas tube, using potassium chloride-brine-xylene-acid. It was found that the method has only got limited effectiveness that is for scale soluble in potassium chloride-brine-xylene-acid, significant portion of the scale still remains in place.

Traditional control methods such as injection of hot oil (e.g. diesel), chemical solvent treatment and scraping are marginally and temporary at best. To exemplify, Messina Corporation [8] used chemical injector and squeeze application in the oil and gas production tubing and found that the presence of undesirable impurities constantly occurred, such as an increase in the level of sulphure in the oil.

Kenneth and McDonough [9] noted that scale of Barium and Strontium Sulphate types, is extremely difficult to remove by existing mechanical or chemical methods. These authors conducted field tests using abrasive jetting technology in removing hard scale. The abrasive material contained sand and water mixture, supplied at 5MPa to a rotating nozzle head spraying the entire inner surface of 89mm diameter of the well tube. Although 50% of the scale was removed, over a 3 days period the remaining scale deposited on the inner surface of the production tubing causing a well blockage, resulting from the sand present in the abrasive material. Moreover, the safety of the personnel involved handling chemicals on the location must have been a prime concern. The abrasive material contained in the fluid may also erode the production tubing over a period of applications. Taliby et al [10] carried out investigations removing hard scales using the “*through-tubing*” technique, which is also based on abrasive jetting technology, via a series of tests from the recesses of side-pocket mandrels using rotating "pipes". This experiment was conducted in North America, the

North Sea, Africa and the Gulf of Mexico. This method however, presented serious drawbacks, which damages and weakens the well production tubing after spraying the solution a number of times due to the solid abrasive contain in the fluid. Cabtree et al [11] carried out laboratory tests removing a hard scale of Calcium carbonate, using a single water jet and plain pipe. Although carbonate scale was removed a considerable amount remains in place. These authors also used a low pressure water (less than 1 Pa) and low velocity (less than 1 mm/sec). With these operating parameters, as noted by these authors, it was tremendously difficult to remove scale, if not impossible.

It is evident from this open literature that these techniques are not ideal and, if successful, the proposed method of utilizing high impact force water sprays could be much more flexible and superior than the techniques currently used. The technique can provide sustained reduction in the capital and operating costs of the plant and provide the ease and effectiveness of reservoir pressure management.

There is, however, no open literature readily available in UK or overseas which can demonstrate the parametric effects of parameters at high water atomiser pressure (typically greater than 5 MPa) and high impact force (typically greater than 10 MPa) with coarse spray size of $350\mu m < D_{v0.5} < 2000\mu m$ for removing scale in the oil/gas well production tube. There is also a lack of sufficient depth and scope to validated CFD modelling relating to water spray-scale removal in order to permit selection/design of atomizers suited to a given well size and operating conditions. The final result of this investigation will address, "sustainability" by: reduced water usage and electric power consumption, improved working environment for employees due to more automation and less manual adjustments on the production field as well as longer equipment life and more compact plant. The scale may also contain radioactive materials such as Radium-226 (Ra-226) and Radium-228 (Ra-228) which may subject employees to radiation exposure.

Experience [GGN,1-2] shows that in 'descaling' processes in metal industries, impact force and surface-fluid temperature difference are the most pertinent parameters in removing surface hard scale. The body of experimental and theoretical or modelling work in this area is far from extensive, especially for those scales which are directly related to the oil and gas wells of down-hole tubing. The forces required for scale removal will be found via AFM (Atomic Force Microscopy) tests. The production tube is normally made of alloy steel which would require greater than 350MPa impact before it starts cracking and water pressures smaller will be used. Furthermore, the volume of water to be used in removing the scale will be kept to minimum, using less than 100 l/min in the shortest possible time. An objective in the design of "spray bar" will thus be to ensure the utilisation of minimum water consumption.

DESCALING SPRAY SYSTEM DESIGN AND ANALYSIS

The investigation is mainly experimental and is divided into two basic phases: Phase1 involves volume of scale removal (VSR) tests under *atmospheric* pressure condition using a simulated down-hole production tube of oil/gas well and Phase 2 is the VSR tests under normal well *reservoir* pressure. Here the proposed simulated design of the Phase1 is only presented. However, before the proposed design of VSR is discussed, it is necessary to briefly highlight the techniques that are used in characterising the sprays and "atomic force microscopy".

(i) Spray Characterisation

It is important to characterise the sprays prior to their utilisation with the "spray bar" in VSR tests and also in order to design the spray bar for orienting the sprays to give full wall coverage. This will be achieved with variation of flow rate, pressure, distance between the selected atomizer and a surface, angle of attack of the jet in relation to the surface, and for at least 2 different types of atomizer and different orifice diameter sizes. High-pressure full-cone and flat spray (pressure jet) atomizers will be used in these tests. As these can be used to produce coarse high impact force sprays with a patternation suited to scale removal application. Sprays must be characterised both in free space and surface impact conditions, so that the scale removal tests can be interpreted. PDA, light scattering, patternators and high speed video imaging will be used in characterising the sprays. The outcome of this work will provide data on: (a) distribution of droplet sizes and velocities, (b) distribution of mass flux for sprays, (c) details for overlapping sprays for multiple atomizers configurations. The results will subsequently be used in designing the "spray bar" system and the VSR experiments described later

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(i)Atomic Force Microscopy (AFM) Techniques

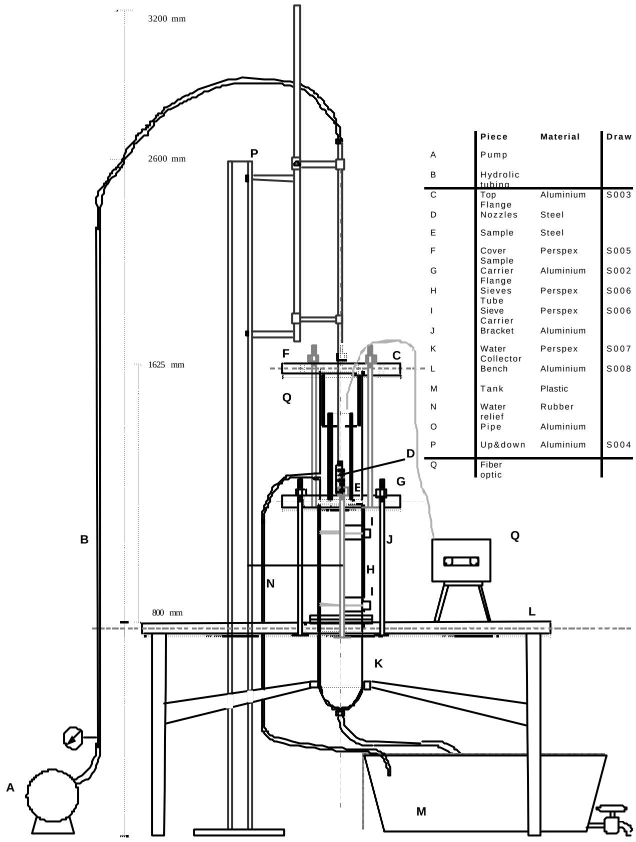
AFM is a relatively new technology invented in 1986 to give topographical images with sub-nanometer resolution in air or a relevant liquid environment [17]. A sharp tip held at the free end of a cantilever is systematically scanned across a surface. As the tip tracks the surface, the forces between the tip and the surface cause the cantilever to bend. The deflection of the cantilever is measured by a device such as an optical lever and used to generate a map of surface topography. The key advantage of AFM, is high resolution images in liquids with little sample preparation, have meant that AFM has provided some very exciting images of biological samples [18] and membrane surfaces of pore structure down to nanometer level [19].

AFM also allows the measurement of the force between a tip and a surface as a function of separation distance at nN-pN sensitivity and nm resolution. As the tip and the sample are brought into contact by means of the extension of a piezo-ceramic scanner the deflection of the cantilever is measured. The deflection vs piezo-scanner extension can be converted to force vs separation if the spring constant is known [20]. The spring constant should be measured for each cantilever used as this can vary substantially from that specified by the manufacturer [21, 22].

The application of the force measurement capability to colloid and biocolloid science is improved by replacement of the tip with a particle of known material and geometry to produce a “colloid probe” [23]. The applicants have been very active in developing this technique and has measured the interaction between 0.75 (m colloid probe and a membrane surface in liquid [24] and extensional liquid properties using the AFN as a nano-viscometer [25], an visualisation of surfaces at nanometer resolution. The development of the cell probe [26] and coated colloid probe are unique to the co applicants. Both colloid and cell probe techniques were used successfully to identify systematic polymeric membranes with low adhesion properties and hence reduced fouling properties in industrial use [27] and studied the effect of surface cleaning on colloids adhesion to surfaces [28].

Descaling Spray System Design and Development, Under Atmospheric Pressure (Phase-1)

The atmospheric pressure Volume Scale Removal (VSR) rig is constructed from transparent 'Acrylic' material as shown schematically in Figures 2 and 3. The pressure inside the 120mm diameter, 2m height Acrylic tube is kept under atmospheric pressure. Each sample, with typical inside diameter of 76mm and 89mm and consisting of scale formations of Calcium Carbonate or Barium Sulphate as typified in Figure 4, is located and fixed in place inside the upper section of 'Acrylic' tube. The 'spray bar' with its atomizers is fixed to a hydraulic water pipe, movable in the axial direction on the centerline of the Acrylic tube. The scale removed by high pressure water sprays (>10MPa), over a given period of time, is then collected downstream of the test sample via a series of sieves. The collected scale is further analysed and weighed thus providing the volume measurement of the corresponding scale. The transparent tube is also enabled the observation of spray structure upon the impaction onto the scale surface using a high speed video camera. The outcome of this work will provide knowledge and insight into volume scale removal (VSR) under atmospheric pressure conditions.



	Piece	Material	Draw
A	Pump		
B	Hydrolic tubing		
C	Top Flange	Aluminium	S003
D	Nozzles	Steel	
E	Sample	Steel	
F	Cover	Perspex	S005
G	Sample Carrier Flange	Aluminium	S002
H	Sieves Tube	Perspex	S006
I	Sieve Carrier	Perspex	S006
J	Bracket	Aluminium	
K	Water Collector	Perspex	S007
L	Bench	Aluminium	S008
M	Tank	Plastic	
N	Water relief	Rubber	
O	Pipe	Aluminium	
P	Up&down	Aluminium	S004
Q	Fiber optic		

Figure 2 Proposed Volume Scale Removal (VSR) apparatus

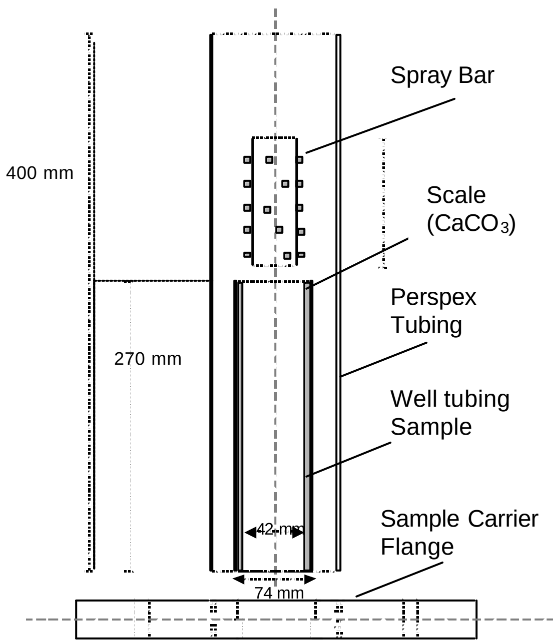


Figure 3 Sample tubular and spray bar inside the top Acrylic tube

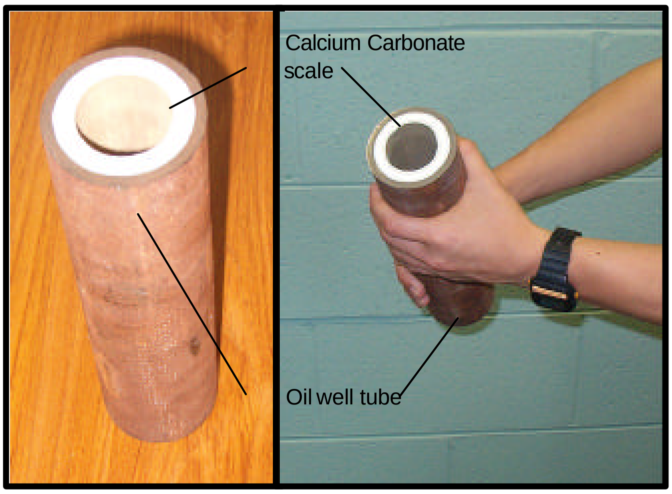


Figure 4 Typical oil well tube with Calcium Carbonate scale

High Ambient Pressure Descaling Spray System Design, Development and Tests (Phase-2)

A pressure vessel, simulating well conditions, up to 20MPa and temperature of approximately greater than 30 ^{o}C will be designed and constructed. Optical access at the top of the tube will allow qualitative observations of spray structure during scale removal tests using high speed video imaging. A series of tests will also be conducted to study the effect of water temperature (<100 ^{o}C) with the surface/scale temperature of about 30 ^{o}C.

The outcome will provide a link between simplified tests carried out, in VSR under atmospheric pressure, and more practical conditions and the high pressure conditions that occur in some situation.

The data obtained from the above will provide systematic information on the effectiveness of high pressure and high impact force water sprays in removing the hard scale, deposited on the inner surface of down-hole tubular of the gas and oil well. The deduced correlations can then be used as design tools for the spray atomizer selection and for various well sizes operating on different conditions. The video observations of the flows, combined with the measurement, will also be used, together with published work, to improve sub-models for CFD codes. The pertinent outcome will be that a validated CFD water spray-scale removal sub-model is to initiate long term exploitation in CFD design tools.

CONCLUSIONS

The utilisation of the simulated apparatus operating under atmospheric pressure (Phase-1) and the prototype design (Phase-2) will provide: (a) a set of design guidelines and procedures for removing hard scale in the oil and gas well production tubes, (b) optimisation in petroleum production processes, (d) reduction in operating cost and increase in oil/gas production rate and, (c) CFD design tools.

It will also be of benefit to: (i) practitioners involved in design and evaluation of equipment in petroleum industries, particularly in drilling and exploration of oil and gas, (ii) researchers in sprays and atomisation science and technology, (iii) practitioners involved in atomizer's design and manufacture and (iiii) the working environment of employees in oil and gas production plant.

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