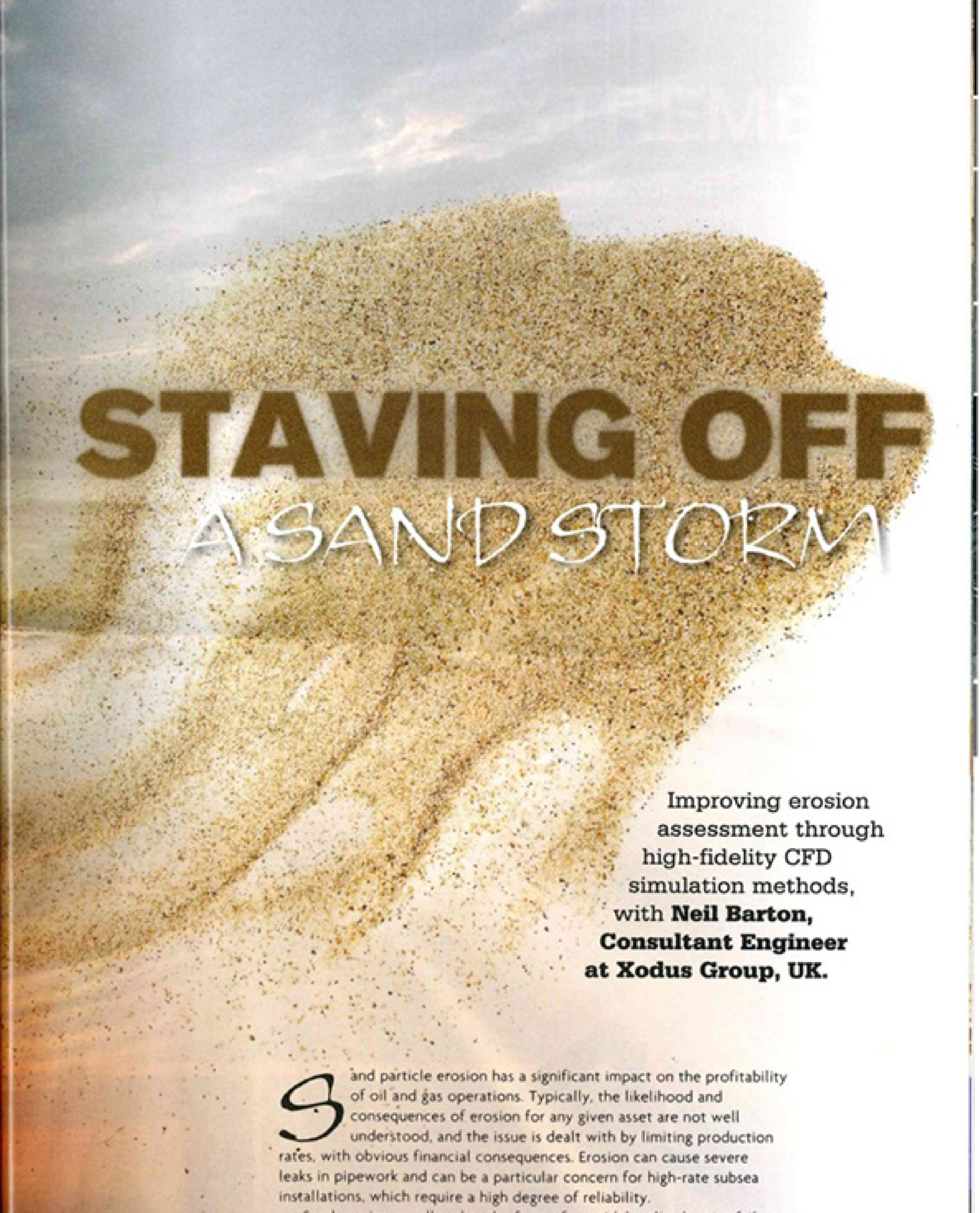


# STAVING OFF A SAND STORM

Improving erosion assessment through high-fidelity CFD simulation methods, with **Neil Barton, Consultant Engineer at Xodus Group, UK.**

Sand particle erosion has a significant impact on the profitability of oil and gas operations. Typically, the likelihood and consequences of erosion for any given asset are not well understood, and the issue is dealt with by limiting production rates, with obvious financial consequences. Erosion can cause severe leaks in pipework and can be a particular concern for high-rate subsea installations, which require a high degree of reliability.

Sand erosion usually takes the form of a rapid, localised, point failure, at a location where the produced flow changes direction or accelerates. In practice, this tends to be upstream of the primary separator at bends, tees, Xmas trees and within and downstream of chokes and valves. Downhole, flow restrictions such as sliding sleeves and ports are vulnerable, as is the filtration media of sand screens.

Various tools are available to measure sand production and its effects, such as sand monitors, ultrasonic wall thickness surveys and sampling. Both measurements and erosion predictions are typically used as inputs to a sand management strategy, and the ability to accurately calculate erosion rates is important both at the design stage and when operating an asset.

Erosion is a complex and sensitive phenomenon, and it can be challenging to estimate erosion rates to a high degree of accuracy. However, it has been extensively studied and the distribution and depth of erosion damage can probably be predicted more reliably than for most other wall loss mechanisms, such as corrosion or cavitation.

In most circumstances, it is reasonable to assume that the erosion rate at any one location will be proportional to the total mass of sand that has passed through the pipe. Also, erosion is highly sensitive to the flow velocity. As a rough rule of thumb, when the flow velocity doubles, erosion will increase six-fold.

As a first approximation, most materials likely to be used in production pipework components, such as carbon and stainless steels and austenitic nickel-chromium alloys, have a similar erosion resistance and it is rarely practical to solve an erosion problem by changing materials. Tungsten carbide is highly erosion resistant, but its use is limited to specialist components such as choke cages. Limited experience of testing thermal spray coatings suggests that they are usually too thin to offer a significant improvement and no such technique has been widely adopted in the industry.

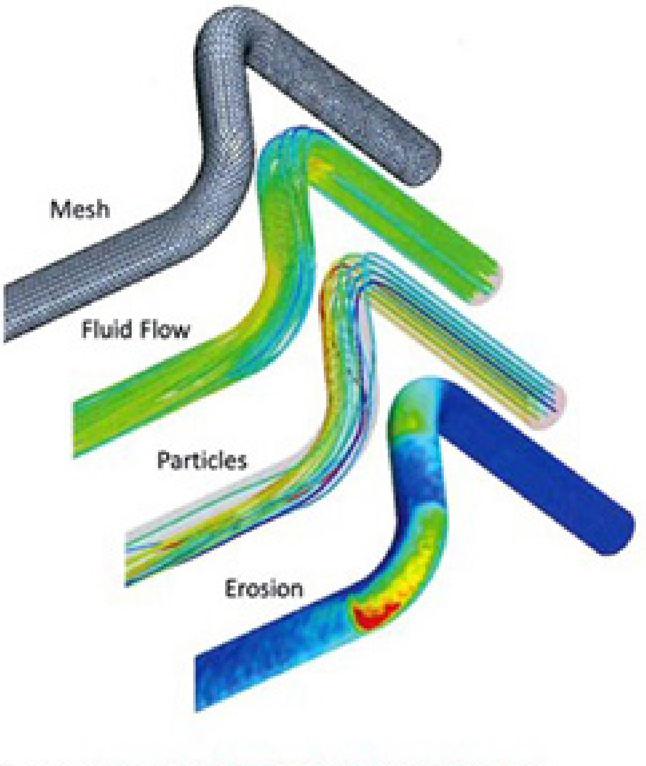


Figure 1. Illustration of the CFD modelling technique.

## Erosion prediction methods

One of the simplest erosion assessment tools is the API RP14E velocity limit equation. This equation is still widely used despite being the subject of significant criticism, as it ignores the effect of the sand production rate and at best it is suitable for basic pipe-sizing calculations.

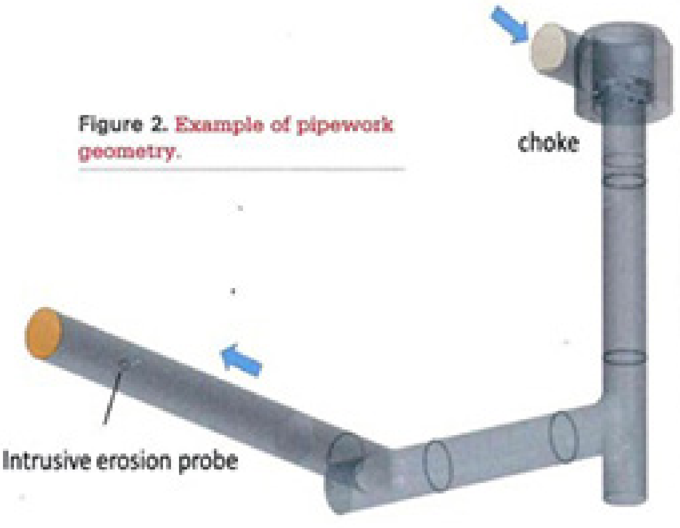
More accurate predictions can be made using a number of correlation-based methods, such as those given in DNV GL RP-0501, the Salama equation and the sand production pipe saver (SPPS) software produced by the University of Tulsa (USA). These methods are essentially equations that predict erosion in simple components, such as single bends or tees, for given flow conditions. They can be regarded as being composed of two elements: a term to predict the severity of sand impacts (referred to in this article as the sand impact model) and a term to predict the resultant damage (referred to as the material response model).

The sand impact model estimates the mass of sand that will impact on a given surface area and the impact velocity and angle, providing inputs to the material response model.

The material response model predicts the mass of material removed from a surface by the sand impacts. Additional terms in the material response model may be included to account for particle size and sharpness effects. The parameters in the model are typically derived from sand-blast tests performed on small coupons of materials and different models have been developed for different materials. In SPPS and DNV GL RP-0501, the model parameters can be changed so that erosion can be predicted in components made of different materials.

These correlation-based methods have the advantage of being quick to implement and they account for most

Figure 2. Example of pipework geometry.



of the important factors affecting erosion. They are particularly useful as screening methods to identify systems that are well below or well above acceptable thresholds. However, they only consider simple geometries that are primarily based on data from low-pressure, small scale tests and their representation of multiphase flow can be simplistic.

Further improvements in accuracy can be achieved by using computational fluid dynamics (CFD) techniques. CFD is a numerical three-dimensional flow modelling technique that has been used in a wide variety of applications in many industries. Figure 1 illustrates the typical approach for predicting erosion in a double bend. Firstly, a three-dimensional representation of the bend is created in the CFD software package. Boundaries and fluid flow conditions are defined and the fluid flow field is calculated. Numerous particles are then injected at the inlet and tracked through the model. When particles hit the walls their angle and velocity is recorded and a material response model – similar to that in, say, the DNV erosion equations – is used to calculate an erosion contour map.

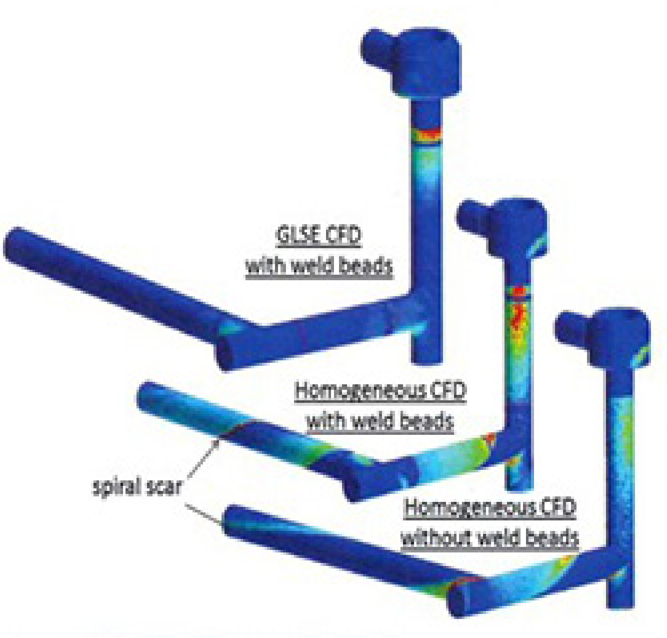


Figure 3. Predicted erosion distribution.

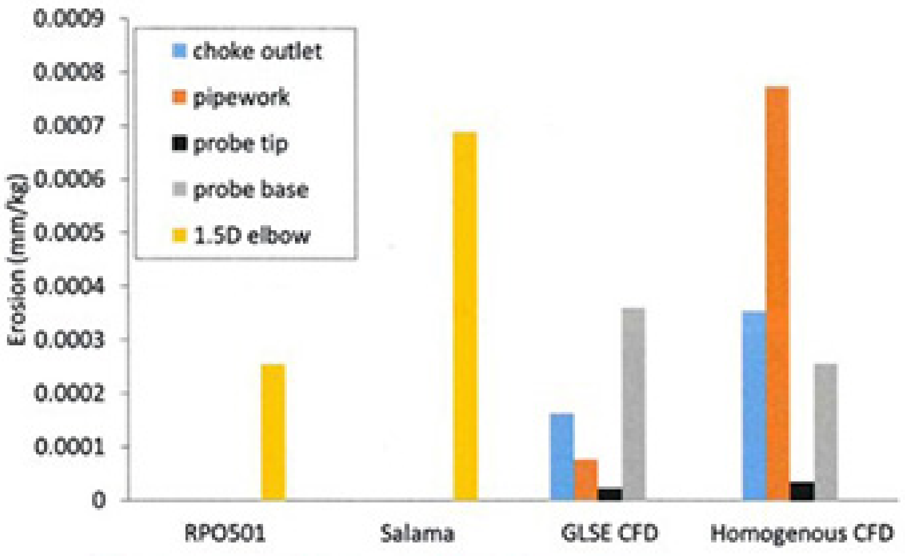


Figure 4. Maximum predicted erosion rates for the example case.

CFD simulations have significant advantages over the correlation-based methods in that they can predict erosion in complex geometries. Early CFD erosion work included models of bends and bean chokes, with later work on more complex geometries, for example, full subsea Xmas tree installations.

Conventionally, gas-liquid mixtures are approximated as a single homogeneous fluid with averaged fluid properties. This approach (the homogeneous CFD method) is relatively straightforward to implement and has been widely used in the oil and gas industry. It identifies the location and depth of erosion scars in both test and field pipework, but can produce overly pessimistic results under some circumstances.

Recent work performed by Xodus (on flow induced vibration of pipework) and a number of others has shown that CFD simulations that explicitly model separate liquid and gas phases can predict multiphase flows realistically. If this is the case, then gas-liquid-sand erosion CFD models (GLSE CFD) should, in principle, be more accurate than the homogeneous CFD method. Some preliminary work has been published by Xodus and others which suggests that this is the case, although further work is needed to fully understand the advantages and limitations of GLSE CFD. This article shows how GLSE CFD predictions differ from those of homogeneous CFD in a typical application; the pipework downstream of a choke in a high-rate wet gas well.

## Case study – predicting high erosion

Figure 2 shows the example pipe section comprising a choke valve, two target tees and a downstream intrusive erosion probe. CFD is frequently used to assess complex pipework configurations such as this, in both topsides and subsea applications.

In this case, a high rate wet gas well has been simulated; this is one of the more arduous duties from an erosion perspective. Both the homogeneous and GLSE CFD methods have been used. An additional simulation has also been performed to assess whether small surface features, such as weld intrusions, make a significant difference to the results.

Figure 3 shows the CFD predictions of erosion distribution and Figure 4 shows the predicted erosion rates along with RPO501 and Salama equation calculations for 1.5D bends operating under similar conditions.

In this case, both DNV GL RPO501 and Salama provide a reasonable, first-pass, conservative estimate of erosion. This may be sufficiently accurate if low sand production was expected or if production at this condition was of a short duration. However, for more critical applications simple equations provide little information on failure mechanisms and they increasingly over-predict erosion as liquid rates increase.

All of the CFD models predict high erosion at the choke outlet. This behaviour is not uncommon when chokes are near-closure and can be a particular problem when high erosion occurs at a flanged joint, where relatively little damage may be required to cause a gasket failure and subsequent leak. This result suggests that the choke has not been correctly sized for the production rate range.

The two tees downstream of the choke cause the flow to swirl down the pipe. In the homogenous CFD models this generates a 'particle rope', which causes a distinct, deep spiral scar. The homogeneous CFD model is highly sensitive to small surface features. For example, adding a 5 mm weld bead at the tee joints changes the location of the spiral scar (Figure 5) and increases the predicted erosion rate by a factor of three. Similar effects can be caused by radiusing the tees or altering the choke opening position.

The overall flow behaviour in the GLSE CFD model is similar, but the unsteady nature of the flow at the tees and turbulence from the choke causes the rope position to vary over time. This spreads particle impacts more widely effectively eliminating the spiral scar.

Similar results have made a significant difference to the predicted acceptable production rate in recent studies of subsea pipework performed by Xodus. The particle roping is a known phenomenon and is believed to be realistic. In principle, the GLSE CFD results should be more accurate. However, there is no known published data from tests on erosion for multiple tees in high-pressure wet gas conditions that could be used to definitively confirm this.

Target tees, such as those used in this example, are often installed in an attempt to reduce erosion. However, both test results and CFD modelling has shown that target tees are only effective in relatively low pressure gas duties. In high-pressure and high-liquid flows, target tees can make erosion worse. In this case study, further simulations could be used to assess the relative performance of elbows and tees.

CFD can also provide a useful insight into sand and erosion monitor placement and effectiveness. All of the CFD simulations show that the sand is thrown out to the pipe walls when it passes through each tee. This concentrates sand near the walls causing high erosion at the base of the erosion probe and low erosion at the probe's sensing tip (Figure 5). In the homogeneous case without a weld bead, the maximum erosion rate is 100 times greater than erosion at the probe's sensing surface (Figure 4) and this can have significant operational implications. Also, the probe acts as a potential source of erosion problems in its own right, which may affect the justification for its inclusion in the installation. Again, anecdotal evidence suggests that this behaviour has been seen in real applications.

## Conclusion

Erosion prediction should be an important element of any sand management strategy and improving the accuracy of erosion models should provide significant benefits, allowing production at higher rates with a higher degree of safety.

Equations and correlation based approaches such as DNV GL RP-0501, the Salama equation and the University of Tulsa SPPS provide a useful and quick screening method but they only model simple pipework geometries such as single bends.

The homogeneous CFD approach has the advantage that it can be used to assess more complex pipe geometries, such as sequences of bends and valves. However, preliminary work has suggested that explicitly modelling the gas, liquid and sand phases can significantly improve the accuracy of CFD erosion predictions.

Work has been published on other CFD erosion prediction methods that use different models to represent the gas and liquid phases, but the optimum approach has yet to be established. Further work is required to help to clarify this issue.

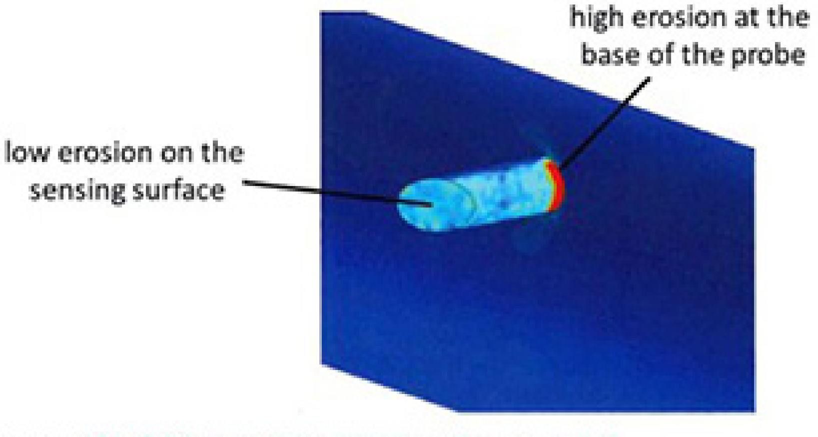


Figure 5. GLSE CFD – predicted erosion on the erosion probe.