LITERATURE REVIEW ON HOW TO SELECT THE OPTIMAL TYPE OF SUCKER ROD FOR A GIVEN APPLICATION

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INTRODUCTION

The goal of a sucker rod is to convey the motion from the downhole pumping unit to lift fluid to the surface. When sucker rod lift is to be used on a well, it is necessary to choose the type of sucker rod that is optimal for the downhole conditions of the given well. Each sucker rod is designed to work in a specific environment, such as a corrosive or non-corrosive environment, and the loads encountered. The purpose of this paper is to report the findings on how to choose the optimal sucker rod for an application, based on a literature review.

DISCUSSION

Types of Sucker Rods

There are three grades of sucker rods that the American Petroleum Institute (API) recognizes, which includes: Grade C sucker rods, Grade K sucker rods, and Grade D sucker rods consisting of Grade D carbon, Grade D Alloy, and Grade D Special Alloy, which may also be referred to as Grade KD. Non-API sucker rods include high strength, fiberglass, and heat-treated sucker rods. The difference between API and non-API grade sucker rods is that non-API sucker rods vary in their material composition based on manufacturer but follow the sizing of API grade sucker rods. (Automated Rig Technologies LTD.)

Common Elements in Sucker Rods

Some of the common elements found in steel sucker rods are Carbon, Manganese, Chromium, Nickel, and Molybdenum. Each sucker rod uses a combination of several of the previously mentioned elements and understanding the properties that each of these elements add to the sucker rod can help to determine what type of sucker rod is optimal for each use. Carbon is the main strengthener of iron and the higher the concentration of Carbon in steel creates a harder metal with a higher tensile strength. Although once the Carbon content exceeds 0.6%, the metal will become more brittle and susceptible to corrosion. (Patterson et al.) Manganese is an element that is always used alongside Carbon and is used to increase the strength of the iron. Chromium is used because it helps to increase the hardenability and corrosion resistance of steel. Nickel strengthens and toughens steel and when used in combination with Chromium, creates a higher resistance to corrosion and a higher fatigue resistance. In addition, Nickel has a fine crystalline structure, causing cracks to develop slow relative to a Carbon steel. (Patterson et al) When Molybdenum is used in steel it increases the hardenability of the steel.

Specifications of Each Type of Sucker Rod

Grade C sucker rods are made of Carbon-Manganese steel and contain the following specifications:

Table 1
Properties of Grade C Sucker Rods

Minimum Tensile Strength	90,000 psi
Maximum Tensile Strength	115,000 psi
Minimum Yield Strength	60,000 psi

The Grade C sucker rods are used in low to medium load conditions and are not susceptible to hydrogen embrittlement.

Grade K sucker rods are made of Nickel-Molybdenum steel and contain the following specifications:

Table 2
Properties of Grade K Sucker Rods

Minimum Tensile Strength	90,000 psi
Maximum Tensile Strength	115,000 psi
Minimum Yield Strength	60,000 psi

Grade K sucker rods intended for the same load environments as Grade C sucker rods, although Grade K sucker rods have been shown to outperform Grade C sucker rods in corrosive environments. (Gipson et al.) In addition, due to Nickel being present in Grade K sucker rods, they are more expensive in comparison to Grade C.

Grade D Carbon sucker rods are made of Carbon-Manganese steel. Grade D Alloy sucker rods are made of Chromium-Molybdenum steel. Grade D Special Alloy sucker rods are made of Nickel-Chromium-Molybdenum steel. The specifications for Grade D sucker rods are as follows:

Table 3
Properties of Grade D Carbon, Grade D Alloy, and Grade D Special Alloy Sucker Rods

Minimum Tensile Strength	115,000 psi
Maximum Tensile Strength	140,000 psi
Minimum Yield Strength	85,000 psi

Grade D sucker rods are intended for wells with moderate loads. Grade D Carbon and Grade D Alloy sucker rods are not recommended in a corrosive environment, although Grade D Special Alloy sucker rods can be used in corrosive environments.

High Strength sucker rods are commonly made from either Nickel-Chromium steel or Nickel-Chromium-Molybdenum steel. These sucker rod generally have a minimum tensile strength of 140,000 psi, although High Strength sucker rods may have varying mechanical properties depending on the manufacturer. High Strength sucker rods are used when encountering higher load conditions, such as in deep wells, although are more prone to corrosion.

Fiberglass sucker rods, also known as Fiber Reinforced Plastic (FRP) sucker rods, in comparison to the previously mentioned steel sucker rods, have more elasticity, are about 70% lighter in weight on a per unit length basis, and are non-corrosive. (Reynolds) Utilizing fiberglass sucker rods can reduce the amount of stress on the surface pumping unit because it is lighter than steel sucker rods, reduce failure from corrosion, and increase production rates due to having a higher elasticity than steel. Fiberglass sucker rods are always used in combination with steel sucker rods and important considerations to account for when using fiberglass sucker rods is the temperature rating of the rod and how crooked the hole is. If the temperature rating is exceeded, the sucker rod is at risk of premature failure and when the hole is severely crooked, pump capacity is reduced from the rod being stretched. (Gibbs)

Some sucker rods are put through different heat treatments to improve the mechanical properties of the sucker rod. There are three main types of heat treatment: Quenched and Tempered, Normalized and Tempered, and Induction Hardened. In the Quenched and Tempered heat treatment, the sucker rod is first furnace normalized, which is when the sucker rod is heated past the upper transformation range then cooled below the lower transformation temperature. Next the sucker rod is quenched, when the sucker rod is immersed in either water, ice-water, brine, or ice-brine, which cools the sucker rod to prevent the formation of pearlite, bainite, or ferrite. Lastly, the sucker rod is furnace tempered, i.e. heated to a temperature below the lower transformation temperature. The benefit of using this process is that the sucker rod will have a martensite microstructure needle-like, fine-grained. (Norris) In the Normalized and Tempered treatment, the sucker rod goes through the same furnace normalizing and furnace tempering that was previously discussed. The benefits of Normalized and Tempered sucker rods is that they will have a strong and ductile microstructure, indicating higher fatigue resistance, impact resistance, and endurance limits. (Norris) Lastly, Induction Hardened sucker rods are first put through induction hardening, similar to the furnace normalizing process, except only the surface layer of the sucker rod is heated, and with electromagnetic induction coils. The sucker rod is then quenched, as previously described. Through this process, the outside layer of the sucker rod has the same microstructure as the Quenched and Tempered process, although the inside of the sucker rod will be softer and have greater ductility. (Norris)

Design Process of Sucker Rods

The American Petroleum Institute developed the API Recommended Practice 11BR, which covers the recommended care and handling of sucker rods, and contains a chart known as the Modified Goodman Diagram, shown in Figure 1 below.

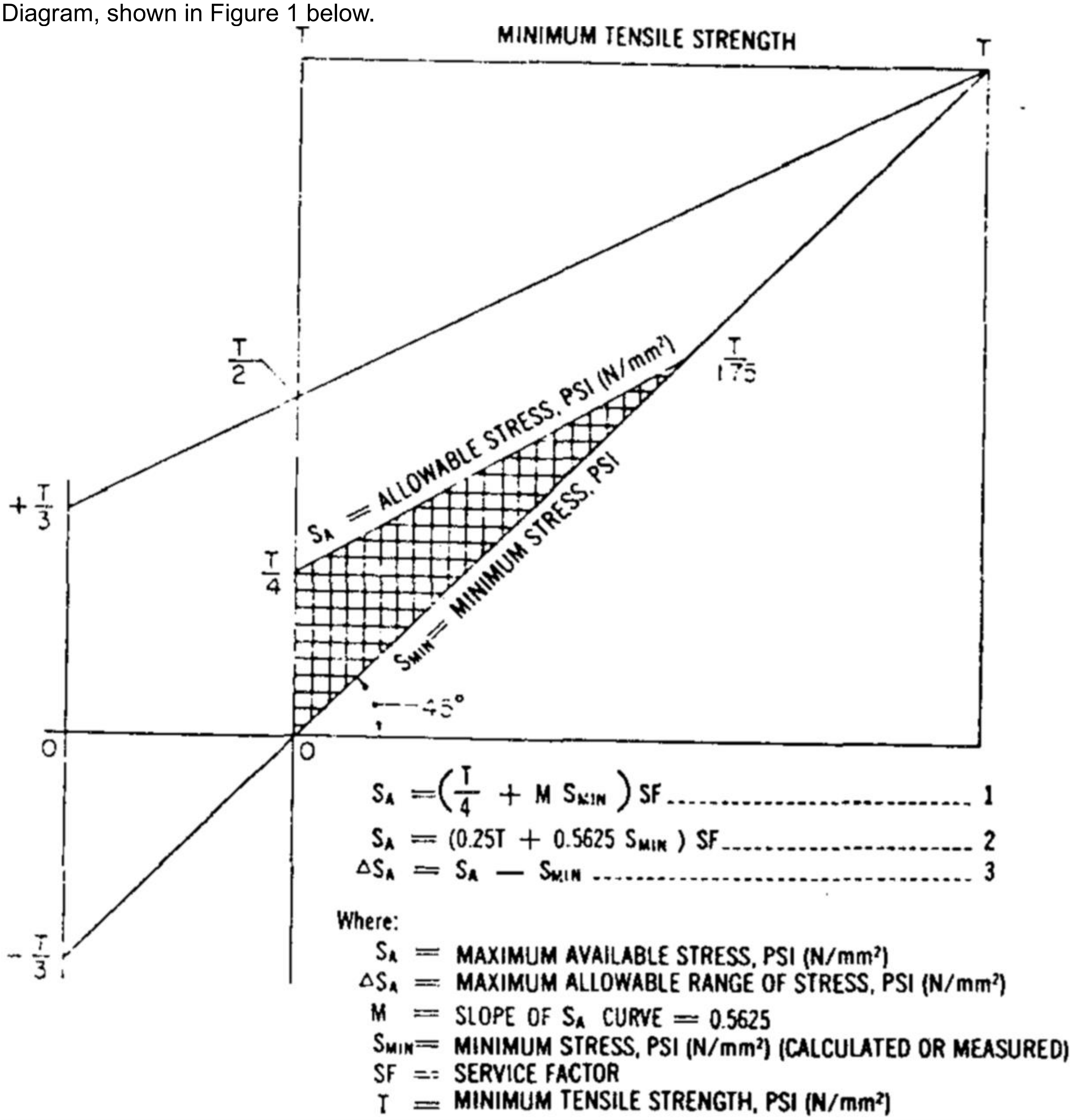

Figure 1 – Modified Goodman Diagram (Hein et al.)

The Modified Goodman Diagram shows the range of stresses over a number of cycles for a given material. Each grade of sucker rod has a specific range of stresses that it can work within, and the intent is to be within the maximum allowable range of stress, ΔS_A ,throughout the life of the sucker rod, to ensure optimum performance and the maximum fatigue life.

In addition, the American Petroleum Institute developed the API Recommended Practice 11L, which is widely used to design sucker rod systems with API grade sucker rods. In order to choose the optimal sucker rod, there are certain factors that must be considered. Some of these factors include the pumping equipment, corrosion, peak polished rod load (PPRL), minimum polished rod load (MPRL), and production rate.

Failure of Sucker Rods

Corrosion-induced fatigue failure is one of the most common seen failures in sucker rods. This is due to the cyclic nature of sucker rod pumping operations in combination with corrosive downhole environments that are encountered. Fatigue failure can be distinguished by the development of a crack perpendicular to the plane of the load or a relatively sudden fracture (Barreto et al.)

There are various corrosion types that can be encountered, including fluid conditions, Hydrogen Sulfide, and Carbon Dioxide. Corrosion from well fluid occur when the water cut is greater than 25% and the pH of that fluid is less than 7.0. (Norris) Hydrogen Sulfide corrosion occurs when present in the form of a gas or in brine and will occur when any amount is present. Carbon Dioxide corrosion occurs when Carbon Dioxide is present in the form of a gas at a partial pressure of 7 psi to 30 psi, or, in brine with a concentration of 600 ppm to 1200 ppm. (Norris)

The following images show a High Strength sucker rod that failed due to corrosion-induced fatigue in an environment with Hydrogen Sulfide, Carbon Dioxide, and low pH.

Figure 2 – Localized Corrosion Morphology (Zhang et al.)

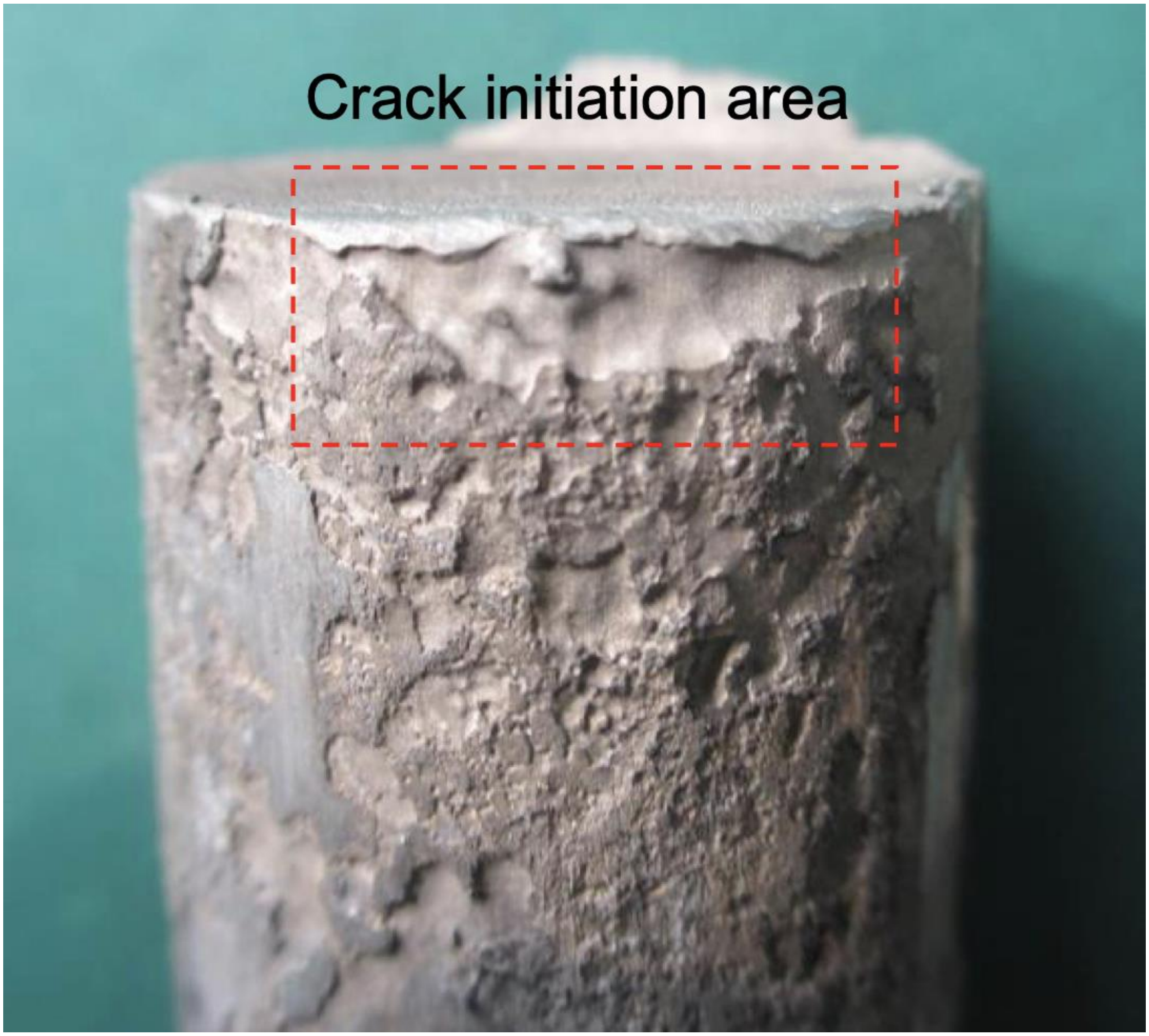

Figure 3 – Crack Initiated from Localized Corrosion (Zhang et al.)

CONCLUSIONS

In conclusion, to select the optimal sucker rod for an application, it is crucial to be aware of the downhole environment of the well and the loads that the rod will endure throughout the life of the sucker rod lift operations. Selecting the optimal sucker rod for a well will have a major impact on the sucker rod lift operation. With the optimal sucker rod, rod failure will be reduced, improving the efficiency and cost effectiveness of the operation overall.

Some solutions to the common issue of fatigue failure include:

- Using sucker rods with high chromium content when in highly corrosive environments (Barreto et al.),
- Using tapered rod strings in deep wells to reduce the stress on the rods above the tapered rod strings, reducing fatigue (Gipson et al.)
- Reducing pump size
- Using fiberglass sucker rods.

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