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Self Case Study -1: Predictive Equipment Failures

Overview

This case study is regarding Conocophillips , multinational energy firm , that funds multiple energy projects in the US. According to them 80% of oil wells in the US are Stripper Wells(oil or gas well that is nearing the end of its economically useful life). These wells produce less volume but at an aggregate level are responsible for significant amount of oil production.

They have low operational costs and low capital intensity - ultimately providing a source of steady cash flow to fund operations that require more funds to get off the ground. Meaning less investment and relatively better outcomes.

The company requires these low cost wells to remain well maintained so that the cash flow remains steady .

But even mechanical and electronic equipment in any field have their shelf life and break down with time. It takes a lot investment of money and resources to get the repairs/replacement done and results in lost oil production .

The aim is to predict this equipment failure depending upon the data given from the sensors so that teams are pre prepared to handle failures as they occur.

Research-Papers/Solutions/Architectures/Kernels

1. **Failure Analysis of the Offshore Process Component Considering Causation Dependence**

Link : https://www.researchgate.net/publication/321137529_Failure_analysis_of_the_offshore_process_component_considering_causation_dependence

Analysis for surface equipment only

Description : This research paper is specifically about the analysis of the equipment failure that occurs on oil rigs that are situated on the sea. The research although only for offshore wells may be able to give us some similarity for stripper wells as well. Offshore oil and gas wells mostly drill below the sea bed for oil and gas.

Isolate the equipment and minimize consequences associated with processing equipment failures.

The research paper discusses about analyzing potential failure scenarios considering causation dependency and also determine which parameter(s) have the most impact on the failure.
The results of the analysis are used to identify most sensitive equipment and their potential failure causes which will help to develop effective risk management strategies focusing on critical equipment.

As per then accidents in the offshore oil and gas industry are mainly caused by human factors(In the sea n number of factors could go wrong depending upon the depth of the seabed), climatic conditions(hurricanes, sea storms, high tides), mechanical failures(Equipment above the sea, equipment below the sea and then the main drilling equipment below the sea bed,longer lines,corrosion from oxygen) and technical lapses.

Examples of a few accidents.

1) July 6, 1988. Piper Alpha incident in the North Sea . Caused by a compromised gas compression module, which resulted in a massive leakage of gas condensate. The leak on ignitions caused explosions and a pool fire on the platform . Over 167 people were killed and 62 survived, with severe injuries.

2) March 21, 2001, Campos Basin, off the coast of Brazil. Two large explosions occurred. The first one occurred mainly as a result of the excessive application of pressure to the

aft starboard drains storage tank, where pressure had risen to 10 bars. When the tank could no longer hold the pressure, a rupture occurred and the fluid inside the tank began to leak. The leakage was followed by a second and more intense blast that was caused by contact between the spilled gas and an ignition source.

3) July 27, 2005, in the Mumbai High Field. During the storm, equipment on board one of the platforms was damaged due to hurricane-force winds, leading to a gas leak and ignition. The subsequent fire devoured that platform and moved onto others.

4) April 20, 2010, The most well-known recent disaster in the Gulf of Mexico. The disaster caused not only the deaths of 11 workers and the near destruction of the platform, but it also led to the decimation of the seafood industry in and around the Gulf due to the unprecedented levels of toxins caused by both the leak itself and the chemicals used to clean it up. The Deep-water Horizon explosion's oil slick spanned 80 miles off the coast of Florida and 140 miles off Mississippi, Louisiana, and Alabama states.

The paper is organised into six sections.

Section 1 provides background information on the importance of safety in offshore operations.

Section 2 briefly captures offshore process operation.

Section 3 details the research methodology.

Sections 4 and 5 Application of the proposed methodology

Section 5 presents the conclusions.

Section 1 Background information on the importance of safety in offshore operations.

Offshore platforms bring with them extensive risks in the form of fires, explosions, and spills. Many of these accidents are caused by hydrocarbon leaks and have major impacts on operations as well as on the workers.

Most of these problems are the direct result of the absence of safety measures and safety training among platform and rig workers. Given the broad impact of these events which occur on offshore platforms but affect people thousands of kilometres away, it is essential to adopt safety measures safety measures based on the relevant information and data as to what causes the the euipment failure that leads to such accidents.

Since the occurrence of the Gulf of Mexico disaster in 2010 the European Commission

(Christou, and Konstantinidou, 2012) has tabled a working paper calling for a concerted effort of all involved in the oil and gas industry to “meet the challenges and threats to oil and gas production platforms through the exchange of information about past disasters to prevent their recurrence in the future”. The working paper has prompted several members of the EU to develop a database on accidents that take place on the continental shelf.

--> **Techniques for Safety Analysis of Offshore Processing**

Several analysis techniques are used to analyze safety and estimate risks. These include quantitative analysis and qualitative approaches.

a) Quantitative risk assessment : The aim is to give the designer sufficient information to enable him/her to build a complete picture of the maritime system properties. At the same time, the quantified occurrence probability of each major failure condition and possible consequences also adressed. Example : Fault Tree Analysis, Hybrid methods, Enhanced Markov Analysis and Bayesian Network.

Fault Tree Analysis : Analysis from the top down. This approach reveals the impacts of basic events on the top event.

Hybrid methods : This approach can be a combination between, fault tree analysis and Markov process or reliability block diagrams.

Enhanced Markov Analysis : This approach groups together uncertainty analysis, sensitivity analysis and Markov analysis.

Reliability Block Diagram : Graphical representation indicating the relationship between the components that comprise a system, including how the reliability and functionality of each component affect the success or failure of the entire system.

Bayesian Network : A directed acyclic graph based on the conditional probability given by the Bayes rule. Bayesian networks are widely used, as a probabilistic tool. Comparing to other quantitative risk analysis methods, the BN provides multi-levels and multi-states dependencies to be taken into consideration. In case of any feature is missing, it can be easily implemented in the network. Similarly, the implementation of new information such as the evidence on one or multiple parameters can be done on mathematical base, which is the Bayes rule.

b) Qualitative safety evaluations : set forth a series of steps that define or identify any potential risks. Information is relayed via charts, tables, fault trees, event trees and other tools. The goal here is to devise some measures to address potential safety. The qualitative ones include Analysis by experts (Domain expert knowledge) and Failure

Mode and Effect Analysis.

Analysis by experts (Domain expert knowledge) : Uses information from previous experiences centred on the same or similar applications.

Hazard and Operability Study(HAZOP): Design review technique used for hazard and design deficiencies' identification affecting the system operability. Uses guide words to describe the deviations.

Hazard Identification(HAZID) : Early hazards detection technique in the conceptual or detailed design stage. Similar to HAZOP

1. Description of the Process ==> All these are mostly surface level equipments.

The focus is on gas processing in this case study. Therefore oil and water treatment systems are not given much attention.

1) Separation:

Separation unit enables a careful separation of the volatile fluids in order to achieve the best possible recuperation of fluid while isolating the water for removal and settling the oil and gas

2) Water treatment : This unit is used for treating contaminated water which contains sand. This is done by using a sand cyclone to isolates the debris. After this, a hydro cyclone is used to separate the oil from water

3) Gas compression unit : This unit is used for re-pressurizing the gas after it emerges from the three-phase separators. The gas compression unit is made up of a centrifugal compressor, heat exchanger, gas turbine, and electric generator.

4) Storage Tank : Storage is used for storing the oil and is susceptible to explosions, fires, lightning strikes, open flames, cracks and leaks. These are caused by operational defects, human error, and terrorism.

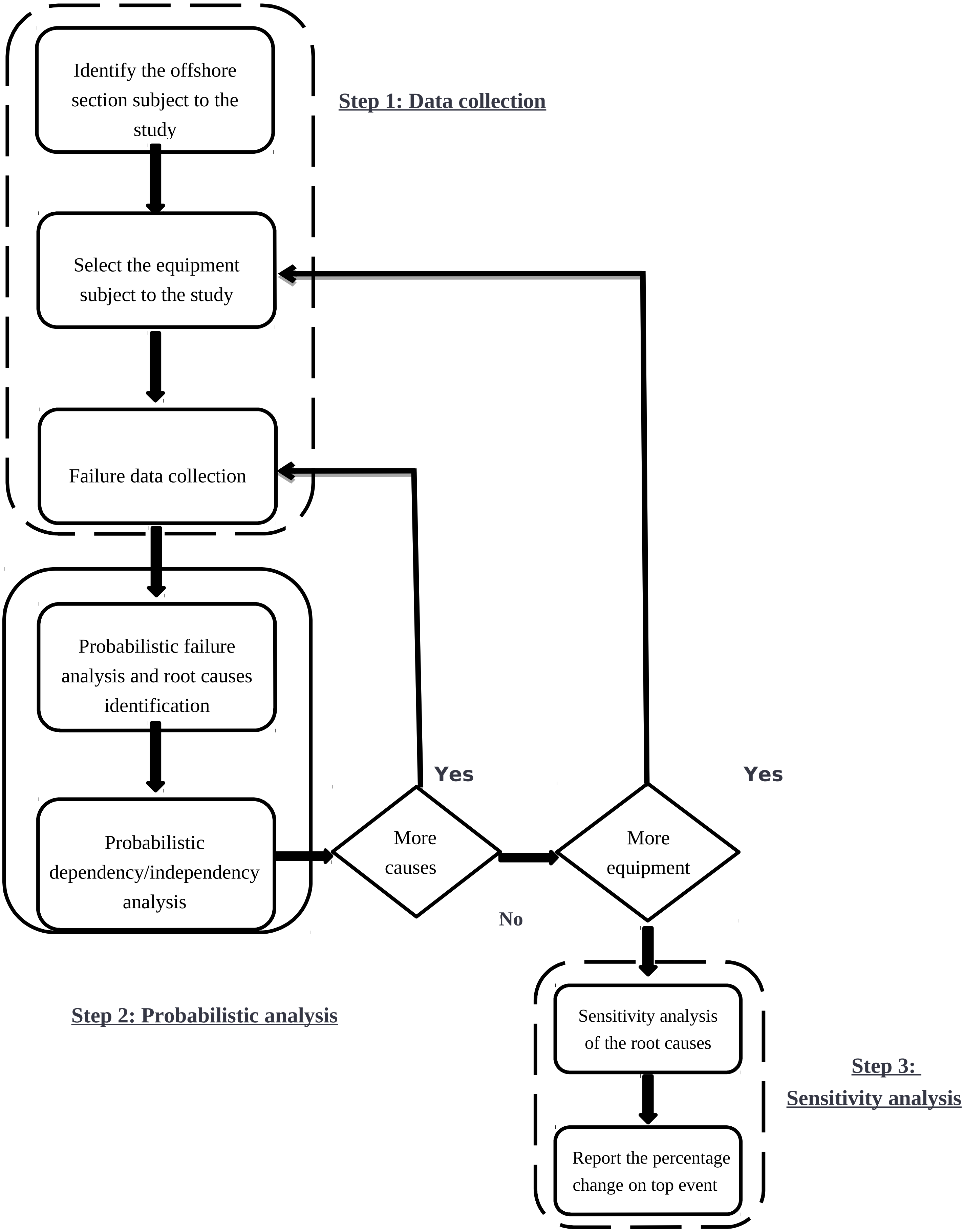
5) Gas dehydration unit : The whole unit functions as a gas drying unit. The absorption column may suffer from foaming.

3) Pipeline : The pipeline moves the gas from the offshore platforms to the processing facility. The main problems include erosion, corrosion, mechanical and material problems, and equipment failure .

3. Research Methodology

A crucial part of industrial processes is the safety system, which functions to prevent certain conditions from further developing into a hazard. Therefore, when safety systems fail, there can be direct consequences ranging from equipment damage, work stoppages, unexpected expenses, environmental degradation, crew injury and death. Safety systems should be operational at all times, regardless of cost or inconvenience to the operator. To achieve non-stop optimal operation of these systems, a multi-objective design is needed. The methodology comprises of multiple phases and shown in Fig. 2. Sections 3.1 to 3.3 describe the steps adopted for this methodology.

Fig. 2. Flowchart for the proposed methodology



Step 1: Data collection

Step 2: Probabilistic analysis

Step 3: Sensitivity analysis

3.1 Step 1: Data collection

Initial hazard identification, should be performed to identify the section presenting relevant potential hazard. In this study, the compression section has been taken as a study subject due to the relevant risk associated with this section in all process industries.

3.2 Step 2: Probabilistic analysis

Bayesian Networks, (BNs) are probabilistic models which are derived from directed graphs. In these models, nodes represent random variables of the scenario or system under investigation. While links between the nodes show the dependence levels of the random variables. The graph structure of the BNs enables complex problems to be decomposed, as modelling can interpret causal relationships in the variables. BNs may replace fault and event trees due to several advantages. BNs can be utilized in the early stages of probabilistic analysis, where the primary aim is to find possible scenarios as well as the linkage of events that might lead to possible adverse consequences. Hence, BNs provide a versatile approach to assessing anticipated equipment failure, as they build model scenarios by asserting conditional probabilities of failure events. Probabilistic failure analysis was performed based on dependencies identification between the root causes, linking the scenarios' elements. It aims to provide accurate analysis where the elements are interconnected in a conditional way. Bayesian networks were chosen as modelling support for this study because of their ability to handle the uncertainty and the ability to represent the conditional interdependency between multiples nodes.

3.3 Step 3: Sensitivity analysis

Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be divided and allocated to different sources of uncertainty in its inputs.

Output of the model, in this case, the top event or the unwanted hazard, can be apportioned(divide up and share out) to different sources of uncertainty in the model input. In this study, the sensitivity analysis is performed in the case of dependency between the root causes and the case of independency. To find out which of the basic events has more impact on the undesired event, a comparative study is performed based on the generated data. Below equation is used for sensitivity analysis calculations:

$$\text{Percentage change} = \frac{\text{Posterior probability} - \text{Prior probability}}{\text{Prior probability}} \times 100$$

Equation(1)

If we want to understand this concept of prior and posterior probability without the formulas we have the below explanation on Quora.

https://www.quora.com/profile/Fred-Feinberg

Fred Feinberg’s response to What is the difference between the prior and the posterior in statistics?

“

the prior is what you believe about some quantity at particular point in time, and the posterior is your belief once additional information comes in.

More specifically, the prior tells you the relative likelihood of different values of some quantity (a parameter) "in the absence of data". The posterior tells you how you'd revise those beliefs "in the presence of data". Note as well that data can keep coming in, so you can 'update' your prior to a posterior, then update THAT posterior to another one, etc.

”

4. Application of methodology to offshore processing system units

This section describes the various scenarios for each system unit investigated. The units include i) Compressor unit.

ii) Heat Exchanger

iii) Turbine

iv) Combustion

v) Generator

vi) Storage tanks

vii) Pipeline

viii) Dehydration unit

Only compressor and heat exchanger analysis are presented in the case study.

Both have events divided into basic and intermediate events

The basic events comprise contain major failure events.

The probability of an intermediate event is based on the conditional states of the basic events.

Basic Event : Break in seal, faulty installation of seal, lubrication decrease, crack in valve plates, weak springs, rotor cracks, rotor jammed, weak installation, casing friction with the rotor, pipeline joints, pipeline, break in blade, worn compressors, gear of the shaft breaks, rotor frictional with casing.

Intermediate Event : Release from seal, release from compressor valve, release from rotor, compressor or casing release, release from the compressor, release from downstream, release from upstream, frictional sparks, high operation temperature, ignition source and gas release.

Example :

The probabilities of over-speeding, lubrication failure, contamination, vibration during start-up and misalignment are the root causes influencing the bearing failure’s occurrence. However, the presence of one or two of them cannot ensure that the bearing will fail.

The root causes are also not contributing at the same level for the bearing failure. All this knowledge can be incorporated through deterministic probabilities in the CPT.

Formulation of the Bayesian networks is based on the conditional probabilities table (CPT)

Table 3 - Elements of BN model for the compressor unit and their probabilities in Descending order.

Basic Events	Failure frequency per year
Gear of the shaft breaks	2.5×10^{-2}
Rotor cracks	2.1×10^{-2}
Rotor jammed*	1.0×10^{-2}
Downstream pipeline joints**	9.0×10^{-3}
Weak installation	6.0×10^{-3}
Upstream pipeline joints**	4.5×10^{-3}

Worn compressors	4.0×10^{-3}
Crack in valve plates*	3.0×10^{-3}
Upstream pipeline**	3.0×10^{-3}
Weak springs*	2.5×10^{-3}
Vibration during start-up*	2.5×10^{-3}
Draining valve left open	2.0×10^{-3}
Lubrication decrease	1.8×10^{-3}
Break in seal	1.2×10^{-3}
Rotor friction with casing	1.0×10^{-3}
Casing friction with Rotor *	1.0×10^{-3}
Break in blade	7.0×10^{-4}
Downstream pipeline**	6.5×10^{-4}
Over-speeding*	5.0×10^{-4}
Contamination*	3.0×10^{-4}
Faulty installation*	3.0×10^{-4}
Misalignment*	2.0×10^{-4}
Lubrication failure*	1.0×10^{-4}

All events are taken from OREDA database , except the single asterisk (*) that are taken from domain expert knowledge, and the double asterisk marks (**) are taken from the reference.

Table 4 - Elements of BN model for the Heat Exchanger tubes Failure and their probabilities in Descending order.

Basic Events	**Failure frequency per year**
External forces	8.3×10^{-3}
High fluid velocity	3.0×10^{-3}
Microbes problems*	1.1×10^{-3}
Fluid hammer*	1.04×10^{-3}
Presence of CO_2, H_2S*	1.0×10^{-3}
Inappropriate filters cleaning	1×10^{-3}
Weak material	1.0×10^{-3}
High temperature	8.8×10^{-4}
Improper dimensions*	0.83×10^{-3}
Improper filters*	5×10^{-4}
Foreign particles in fluid*	4.2×10^{-4}
High pressure	4×10^{-4}
Vibration	0.4×10^{-3}
Surface deposits	3.1×10^{-4}

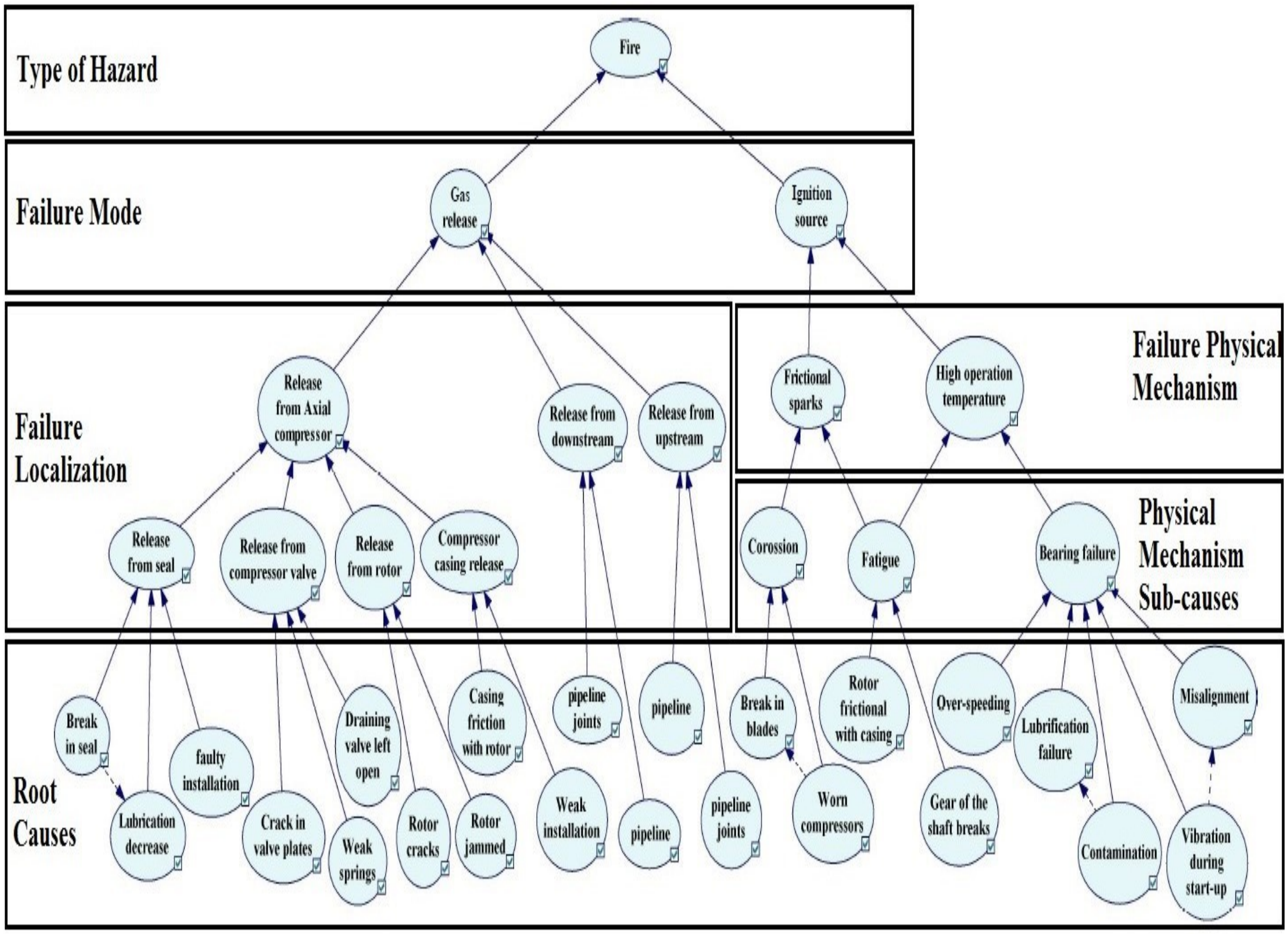
Presence of sand*	2.3×10^{-4}
Cavitation	2.1×10^{-4}
Inadequate materials*	0.2×10^{-3}
Material fatigue	0.2×10^{-3}
Draining not performed	0.2×10^{-3}
Baffle failure	0.1×10^{-3}

All events are taken from OREDA database , except the single asterisk (*) that are taken from domain expert knowledge, and the double asterisk marks (**) are taken from the reference.

5. Results and Discussion

As can be seen in the shown in below figure, fire is assumed to be the top event scenario to occur in the unit, (model was constructed using GeNie software). By employing the basic events data shown in Table 3 compressor unit, both the top event scenario failure probability and the intermediate event conditional probability table (packaged by Subject Matter Experts) were determined. For the top event scenario, the failure probability was calculated as 8.39×10^{-4} occurrence/year in the case of basic events (BE) or root causes independency. In the below figure, the root causes dependencies are represented by dashed arrows to differentiate them from the other dependencies. In the case of BE dependencies' consideration, the probability of fire is 7×10^{-3} occurrence/year. Considering the root causes dependencies evidently has a big impact on the probability of hazard.

Bayesian Network for the compressor unit (BE dependencies in dashed arrows).



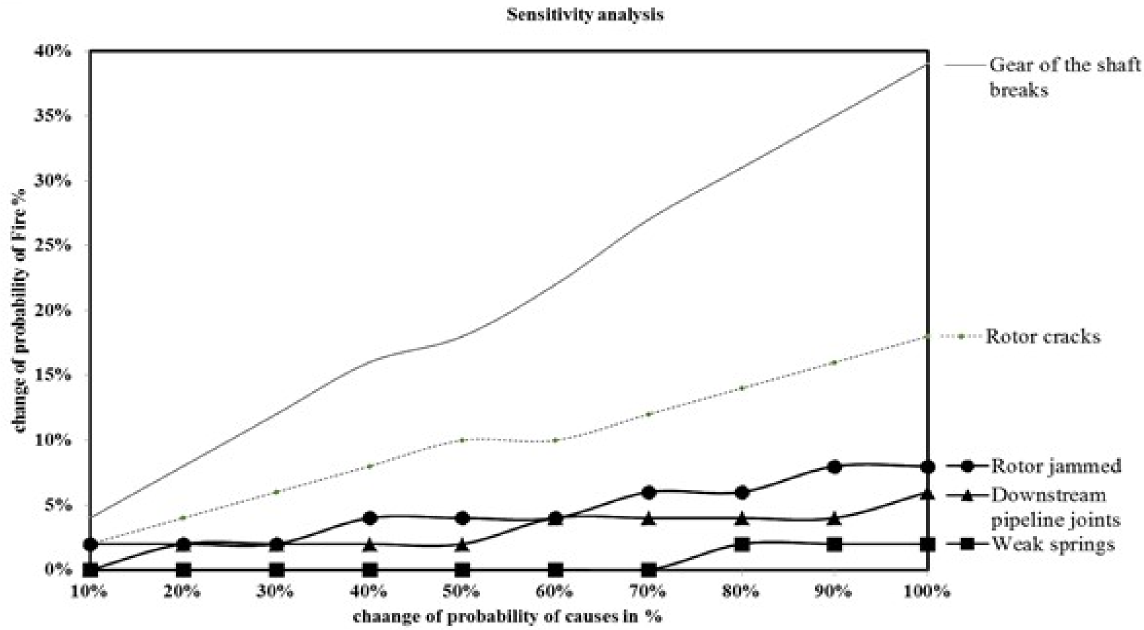


Fig. 4 - Sensitivity analysis of the compressor in case of independency.

With independency, all basic events are considered in order to pinpoint the elements which are more sensitive than the others. Fig.4 highlights elements which are sensitive in cases of independency. As we can see by the increasing slope on the graph for each element, the gear of the shaft breaks and rotor cracks emerge as the most sensitive.

When the element percentage rose from 10 to 100%, the probability of fire also rose. For gear of the shaft breaks, when the increase was 100%, the probability of fire rose to 39%. For rotor cracks, when the probability of failure rose 100%, the probability of fire rose to 18%.

Similarly analysis for other basic events is done.

The graph was created using the equation for sensitivity analysis. The percentage of each element increased from 10% to 100% by a step of 10%, while equation (1) was used to determine whether there was a change in terms (i.e., rise or fall) in the percentage of fire probability.

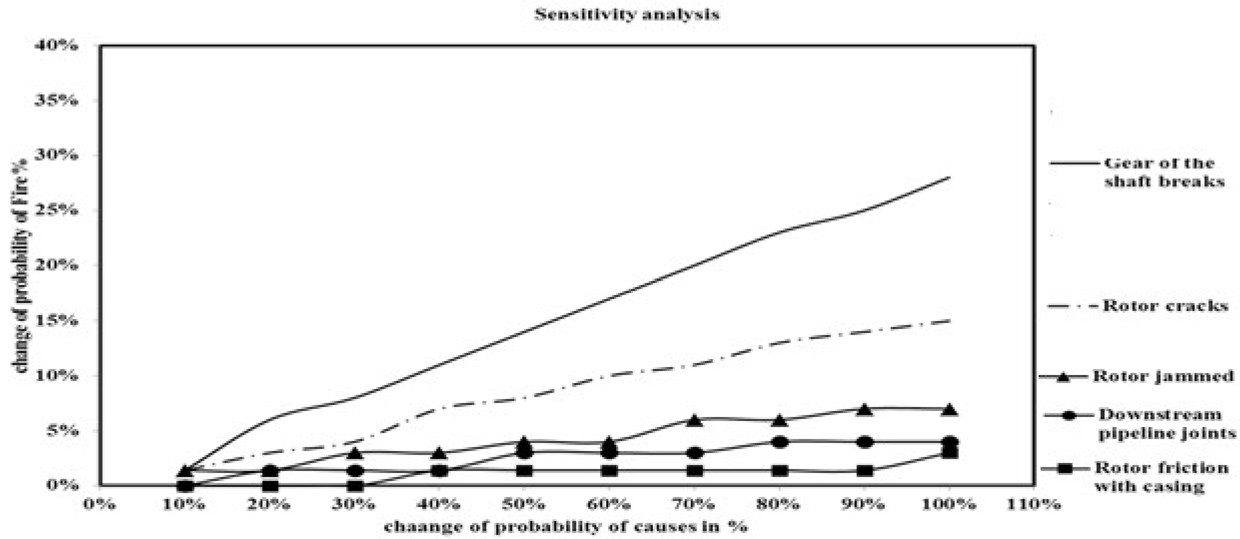


Fig. 5 - Sensitivity analysis of compressor in case of dependency.

For dependency cases, lubrication decrease and break in blade were not considered, as both of these occurrences are classified as intermediate events and we only include basic events.

Fig. 5 shows elements that are sensitive to dependency. As can be seen, 11 elements show as being sensitive, but the most sensitive elements are gear of the shaft breaks and impeller cracks. This is determined by the rise in the steepness of each element's shape. And we make notice of mostly the elements that are sensitive more than the others.

When each element's percentage rose between 10 and 100%, the probability of fire rose likewise. With gear of the shaft breaks, when the increase reached 100%, the fire probability rose by 28%. With impeller cracks, the fire probability stood at 15% when the probability of failure rose100%.

A similar analysis one for other events that turned out to be not as sensitive as the above two given events.

Same steps used to formulate Fig. 4 were also used to formulate Fig. 5 .

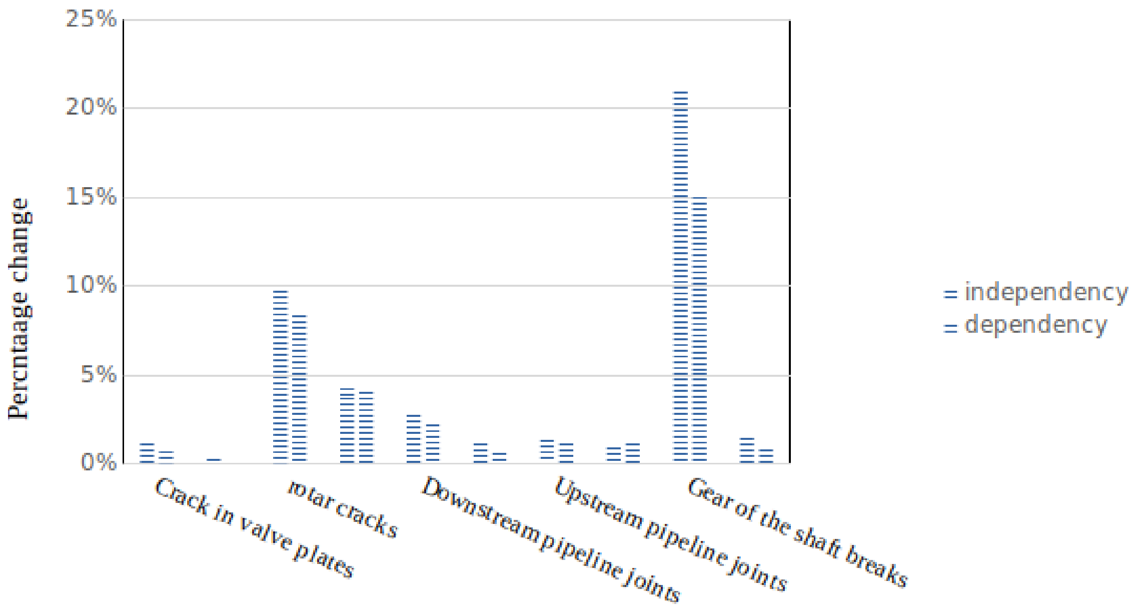


Fig.6 - Comparison of average percentage change for the dependency and independency relationship of the elements.

Fig. 6 was derived from Fig. 4 and 5. In Fig. 6, we can see the percentage changes for similar elements where there is either dependency or independency. So, for instance, we can see that gear of the shaft breaks show a higher percentage in case of independency (21.2%), while rotor cracks show a higher percentage in case of independency (10%). Fig. 6 was obtained by first taking the average for each element according to dependency and independency, and then comparing them to see which elements have greater percentage changes.

Now this was only for the **compressor unit .** They repeat this for the **Heat exchanger .**

Summary :

The validation or the credibility of this study can be recognized due to the fact that this study is derived from a domain reference, which is OREDA(The Offshore and Onshore Reliability Data project) database, coupled with domain expert knowledge of dependencies identification and quantification.

For a compressor under a state of independency, it was determined that 11 elements were sensitive. Of these 11 elements, the gear of the shaft breaks and rotor cracks were the most sensitive. For the compressor under the state of dependency, 11 elements were sensitive. Of these, the gear of the shaft breaks and rotor cracks were the most sensitive. The reduction percentage of each element under independency and dependency causation were also examined. It was determined that the gear of the shaft breaks and rotor cracks had the higher reduction percentage, as shown in Fig.7. Observe that reduction only during dependency causation.

Here Bayesain Network is used because of it’s ability to model causal dependencies, handling of uncertainty in the data, and a simple visual illustration of accident causation process. The BN technique also provides additional capability to update the estimated accident probability once new data/evidence becomes available, it also enables root cause diagnosis given an accident occurrence.

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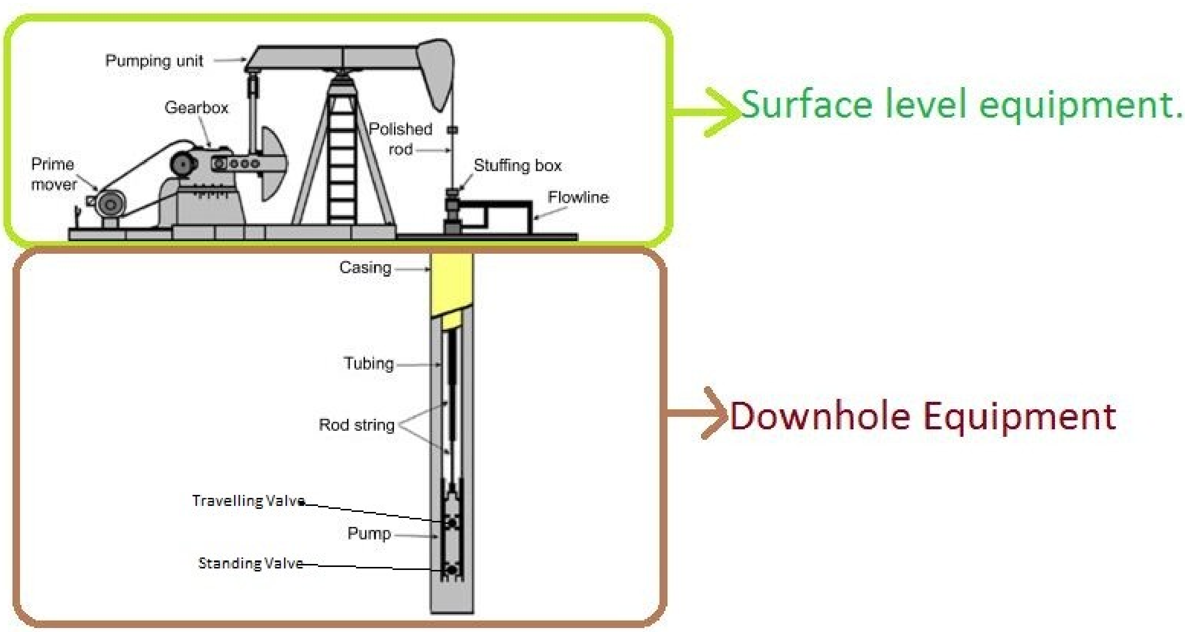
The above research paper considers the equipment only for the offshore rigs and wells and that too the processing part which can be considered surface equipment and not the downhole equipment. Mostly the Compressor unit, Heat Exchanger,Turbine,Combustion,Generator,Storage tanks,Pipeline,Dehydration unit all are surface equipment all done after the oil and gas extraction.

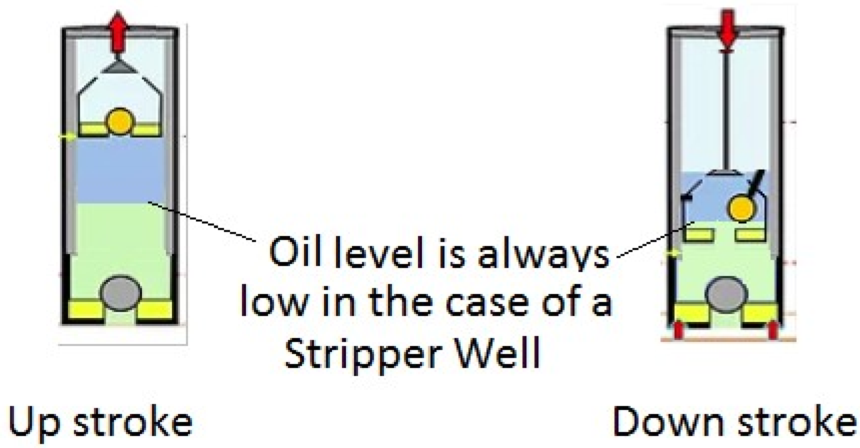
In the below links , let us understand the look at the downhole equipment.



Other links / videos / that have definitions, information regarding the given case study and the issues that are faced:

What is a stripper well ?

A well that is still in operation, but towards the end of its working life, since being marginally viable from a financial point of view. In figures, an oil stripper well will produce up to 10-15 barrels per day averaged over a 12 month period.



https://drillers.com/what-is-a-stripper-well/

Causes of Oilfield equipment failures :

•Improper use
•Metal fatigue
•Inadequate maintenance
•Corrosion
•Overstress
•Welding defects
•Design defects
•Manufacturing defects

Some of the most common types of injuries resulting from oil field accidents caused by equipment failure include:

•Neck and back injuries
•Spinal cord injuries
•Head injury

•Loss of limbs
•Broken bones
•Burn injuries and electrocution
•Exposure to toxic chemicals
•Wrongful death

https://www.bandaslawfirm.com/personal-injury/work-injuries/oil-accidents/equipment-failure/

The most common pump used in the Oil and Gas Industry

The most common type pump used in stripper wells is Reciprocating plunger pump
Reciprocating plunger pump ==> This is the most common type of pump that is used in the industry specially the old wells that have now become stripper wells. There is a high probability that a plunger pump is being used that uses the artificial lift method.

https://en.wikipedia.org/wiki/Plunger_pump

For high pressure scenarios , it is better to use plunger pump rather than a piston pump.

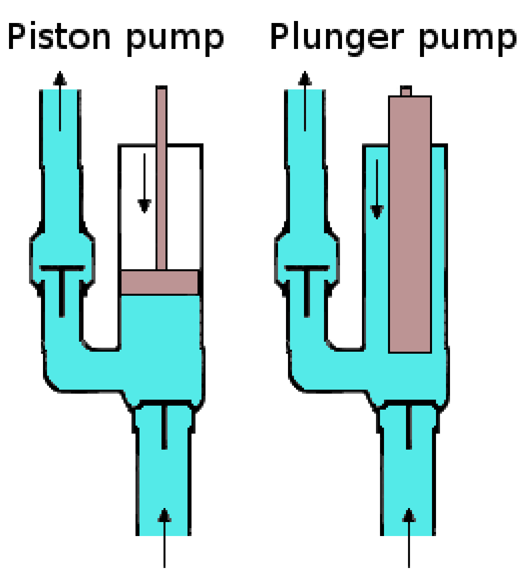
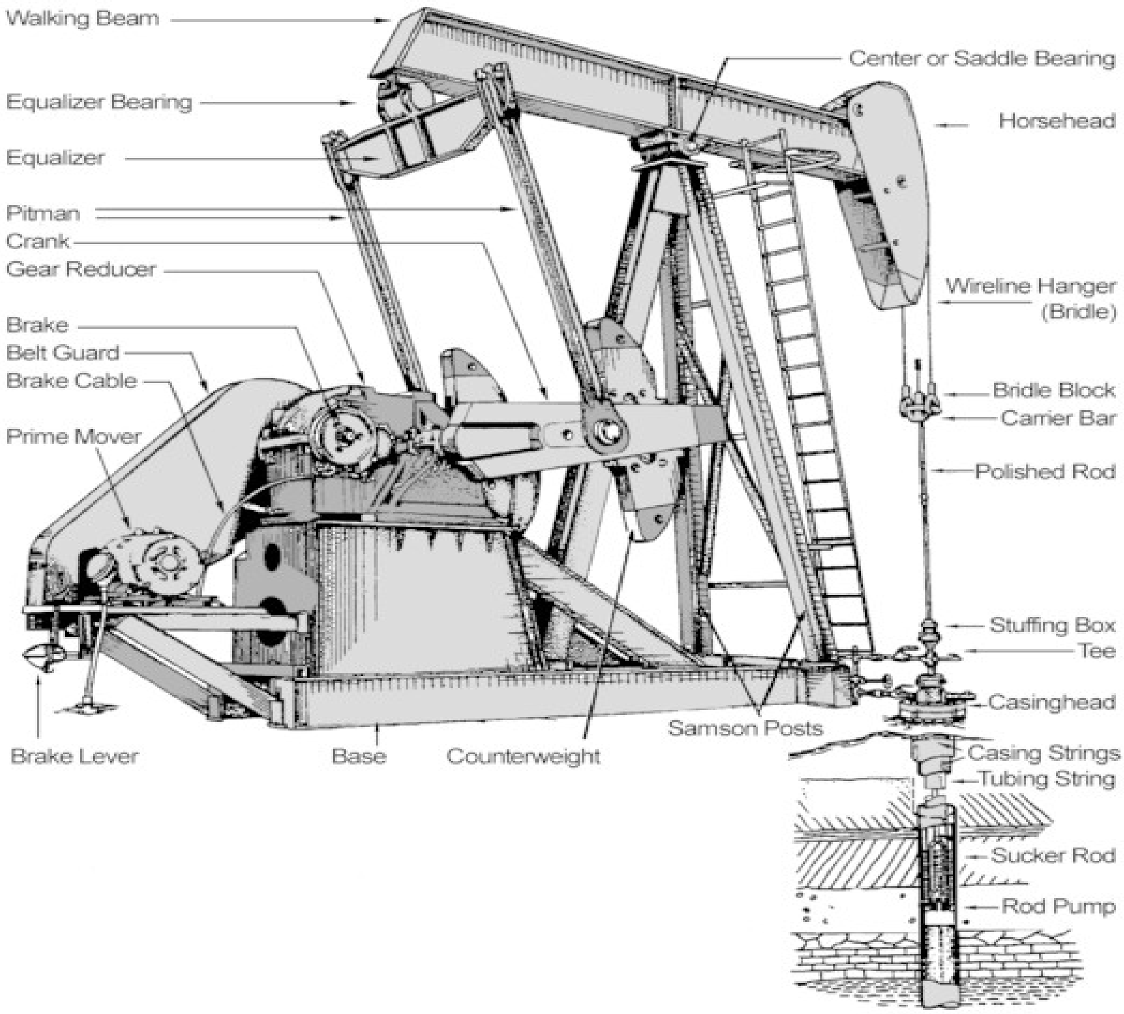
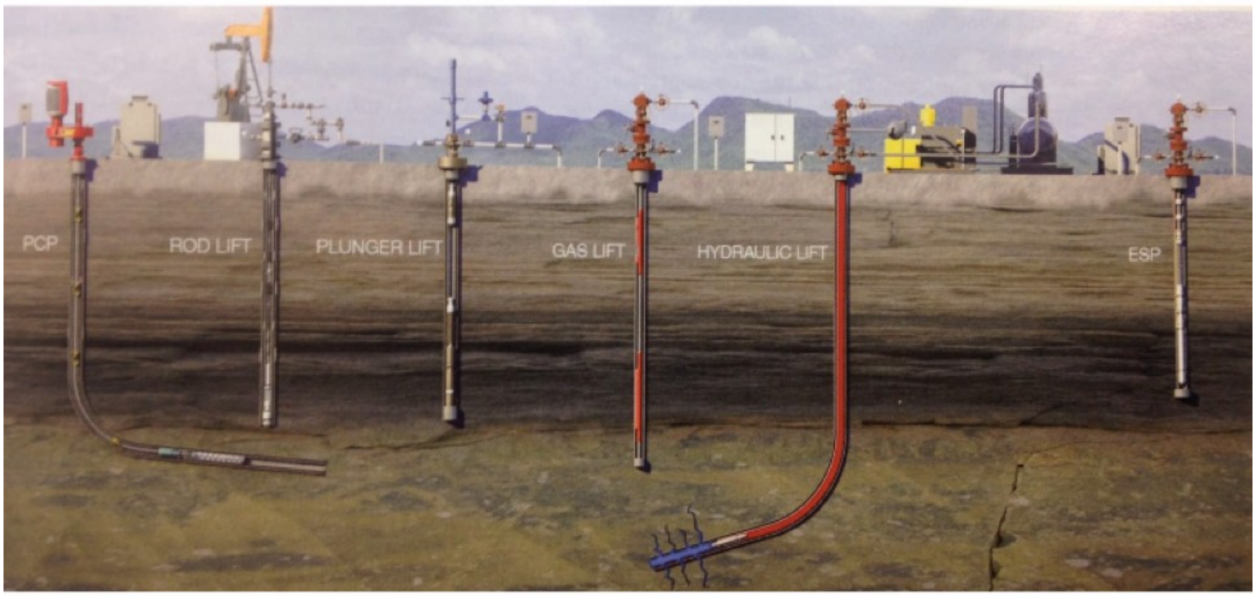


Diagram of Beam pumping unit : https://production-technology.org/beam-pumping-unit/



Examples of Artificial Lift



A demo of Pumpjack system (Rod Lift or artificial lift) :(The Downhole Equipment)

2 valves , plunger valve or travelling valve and standing valve.

How does the process work ?

During the down stroke pump action , the travelling valve hits the fluid(or gas if it is high pressure) and comes up which lets the oil in into the barrel to be carried up during the up stroke pump action .

During the up stroke pump action the travelling valve closes due to weight and pressure and the fact that the plunger is moving up. Hence it does not let the oil that went in the barrel leave.In a way the oil is actually supported by the travelling valve which does not let oil that entered the barrel(during the downstroke) go down . This is just life a lift. That is why this method is known as the Artificial Lift Method because we are not sucking the oil here by creating vaccum and speeding the corrosion , we are letting the oil in on it's own and then pulling it up like an elevator.(Artificial lift is a method used to lower the producing bottomhole pressure (BHP) on the formation to obtain a higher production rate from the well.Artificial lift can be used to generate flow from a well in which no flow is occurring or used to increase the flow from a well to produce at a higher rate.)

While the plunger is moving up with the oil , a vaccum and suction like effect is created due to which the standing valve is opened and lets the oil from the well into the tube.

The again in the next downstroke, due to pressure the standing valve is closed and does not let the oil that was taken in during the upstroke , leave during the downstroke.

So , when one valve is open , the other one is closed. For backup instead of one valve there can be a double valve system.

In this kind of pump there should be long and slow strokes. If there is an attempt to pump more and do fast then it results in sand depositing and corrosion.(Similar to sandblasting when high speed sand hitting the metal can corrode the rust but also the metal.)

You will also not get the full output as with speed pumping a lot particulate matter and gas will be introduced into the pump so we will not get full oil in our pump barrels. And when you do downstroke, then because of the oil not full we create a phenomenon known as Fluid Pound(the shock that is created when the valve hits the oil) that mostly occurs on Stripper wells due to lesser amount of fuel. Fluid pound cause a lot vibration throughout the downhole equipment and causes a lot of damage to the internals of the pump barrels and valves. When the surface equipment, specially the wireline and the rod hanger vibrate horizontally a lot, we can say that there is Fluid Pound.

So keep the strokes long but not fast. This helps in better efficiency and lesser wear and tear and better maintenance.

https://www.youtube.com/watch?v=3y_LZq_yzzA&feature=emb_rel_end

More about Fluid Pound :

Whenever there is a case that there insufficient oil to fill the pump barrel , the well should have it’s run-time reduced so the daily pump capacity better matches the fluid inflow from the reservoir.

We know that the less the oil flow in the pump barrel, the more the fluid pound because the less the oil flow , in the barrel, the level of oil will be that low and the plunger will have that gained that much momentum during the downstroke. And the travelling valve will hit the fluid with that much force immediately releasing pressure that had been building up before the valve opened(upon hitting the fluid).

And this sudden pressure creates a shock to the rod string as the load

(https://www.quora.com/profile/Brad-Heers A2A: Load is simply another term for force. So as an example, your body weight is a load.
Stress is force/area.)

is rapidly released during the downstroke causing the lower rods to buckle and contact the tubing walls - which mechanically wears away the metal & also wipes off any protective corrosion inhibitor films on the metallic surfaces - both which lead to increased rates of Rod-Parts & Tubing Leaks. Fluid Pound beats the pump out and leads to increased rates of pump failures (damaged balls and seats, cracked TV cages, and worn plungers/barrels due to the increased side loadings).

The weight on the rod string can suddenly drop thousands of pounds in a fraction of a second. This condition should be avoided because it causes extreme stress. Slowing down the pumping unit, shortening the stroke length or installing a smaller bottom hole pump can correct this problem. (https://www.glossary.oilfield.slb.com/en/Terms/f/fluid_pound.aspx)

Also, as seen in this video (https://www.youtube.com/watch?v=I74PMMZUgfc), the pumping efficiency dramatically reduces after the well enters a Pumped-Off state (only 8% effective fillage in this example). With 100% pump fillage, the other-all system efficiency (i.e. the amount of useful work done at the pump divided by the total electrical energy input at the motor) is usually only 35-50%. With the pump in the current state of only 8% effective fillage, the overall system efficiency has dropped to 3-4%!

So the unit is going up-and-down, wasting electricity, shorting the life of the pump/rods/tubing--yet nothing of value is being derived from all this additional unnecessary pumping. The same production could be made with less run-time.

Reasons for incomplete pump fill has mainly 3 reasons :

1) Not enough liquid to fill the pump barrel.

2) <u>Gas Interferrence :</u> This happens mostly in wells that are producing more gas than oil and we are unable to separate the two before they enter the pump. Both the gas and oil fill the pump during upstroke. Gas being light does not let the oil fill in full .This means a large portion of the downhole stroke is wasted compressing and expanding gas instead of displacing fluids.In its worst condition gas interference can manifest as "Gas Lock" where neither valve in the pump opens during the stroke and the pump just expands and compresses gas the whole stroke. Gas interference is the kryptonite of rod pumping wells.

3) Flow into the pump intake is choked due to gas deposites or sediment deposits and blockages.

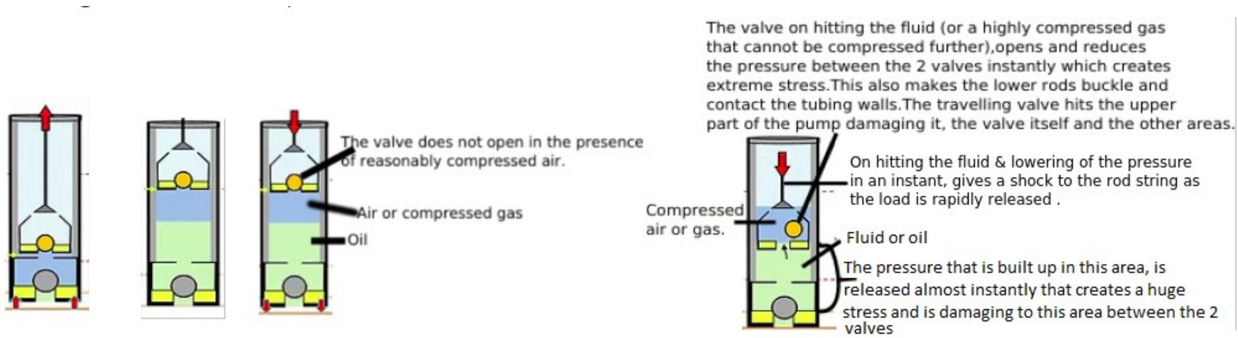
<u>The less the oil in the barrel , the more the Fluid Pound and the faster the wear and tear happens within the downhole well equipment and we know that the condition of less oil happens mostly when the well is a Stripper Well.</u>

<u>A full flowing well will have very less to no Fluid Pound as the plunger does not gain that much momentum (and that much pressure between the two valves is not created) when the plunger meets the oil sooner because the level of the oil in the barrel is high.</u>

<u>Fluid Pound is measured by Dynamometer cards .</u>

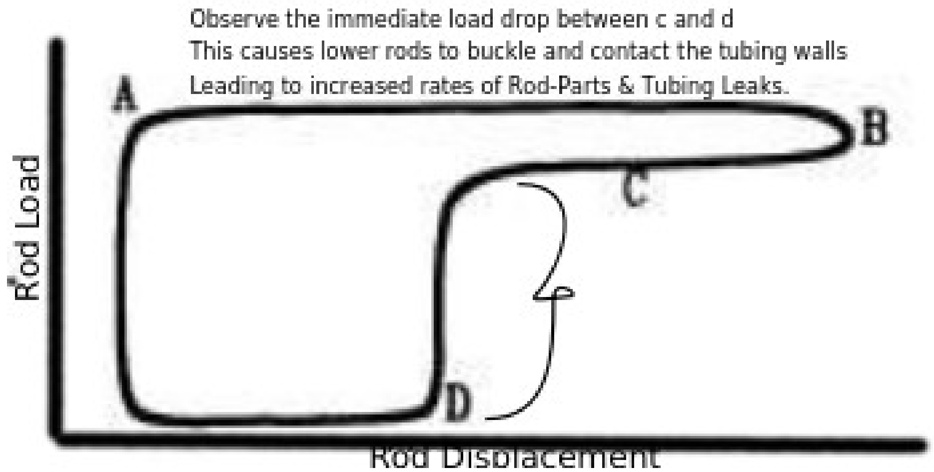
www.downholediagnostic.com ==>

Dynamometer is a diagnostic device used on Sucker Rod Pumped Wells that measures the load on the top rod and plots this load in relation to the rod position as the pumping unit moves through each stroke cycle.

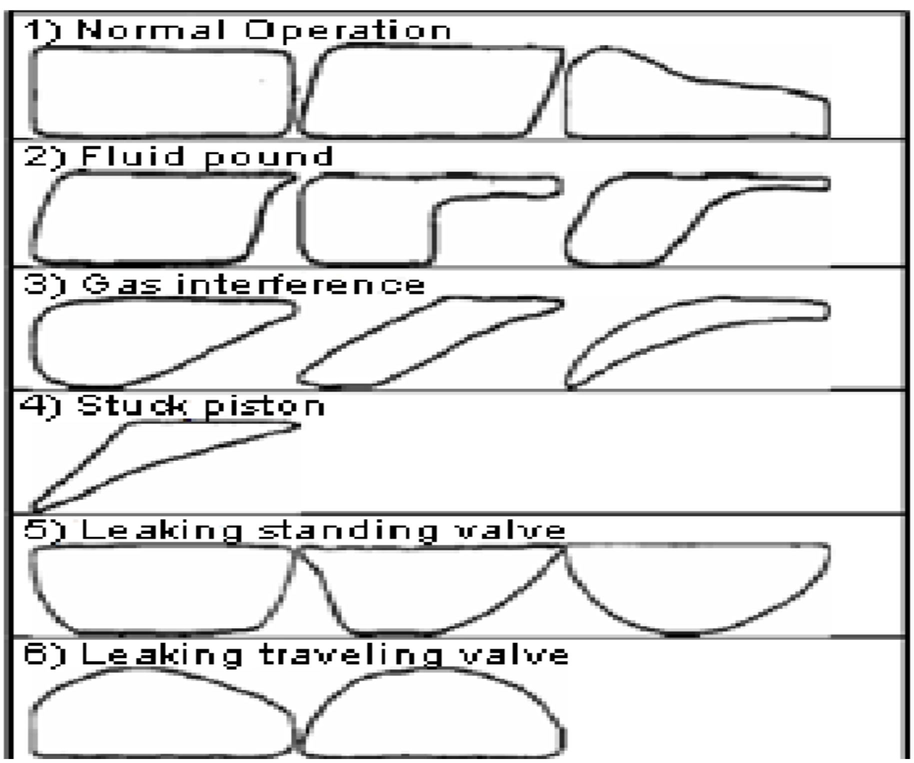


A B C D

Below is a reading from a Dynamometer during Fluid Pound:



Dynamometer readings for all the causations of low oil outputs



Affects :

Fractured nickel-carbide standing valve seat from fluid pound

Other causes of downhole equipment failure :

https://www.slideshare.net/RamezMaher/managing-downhole-failures-in-a-rod-pumped-well

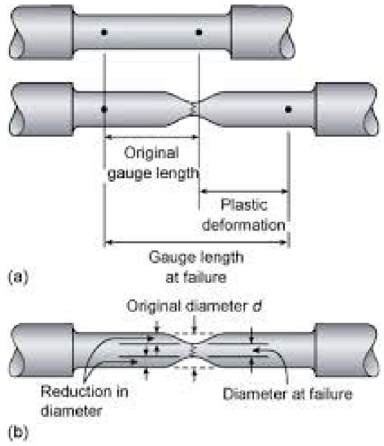
Issue : Calcium Carbonate Depostion due to high water formation .(CaCO3)

STUCK STANDING VALVE DUE TO SCALE

Remedy : increase the wellhead pressure to 150 psi(Pound-force per square inch)

Issue : Sucker rod failures :

1) Tensile Failure : Using improper types of rods creates excessive tension causes rod elongation .



2) Corrosion failure : Rod corrosion due to the CO2 or H2S or Acid. The surface area at a higher risk as O2 is the most corrosive to metals followed by Co2 and then H2S.Acid producing bacteria also causes corrosion.

CO_2 and H_2S Corrosion in Oil Pipelines

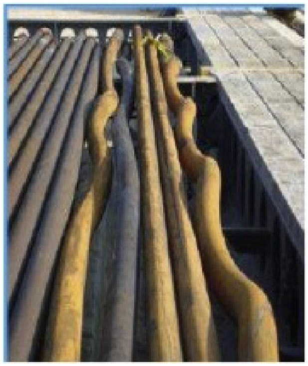
3) Mechanical Failure (Fatigue): Improper make up , fluid pound , old rods.

FATIGUE

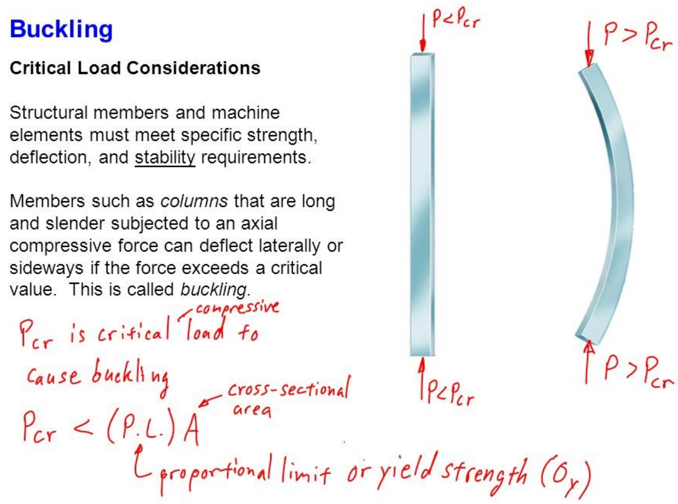
Valve rod guide damage
Due to buckling

TENSILE FAILURE

4) <u>Rod Buckling :</u> This happens due to compression loads in the down stroke.(The rod should be under tension in all conditions). Sudden removal of tension causes this .This results in rod tubing wear, sucker rod failure . Reasons: High speed pumping, fluid pound , heavy viscous oil, pump tagging.



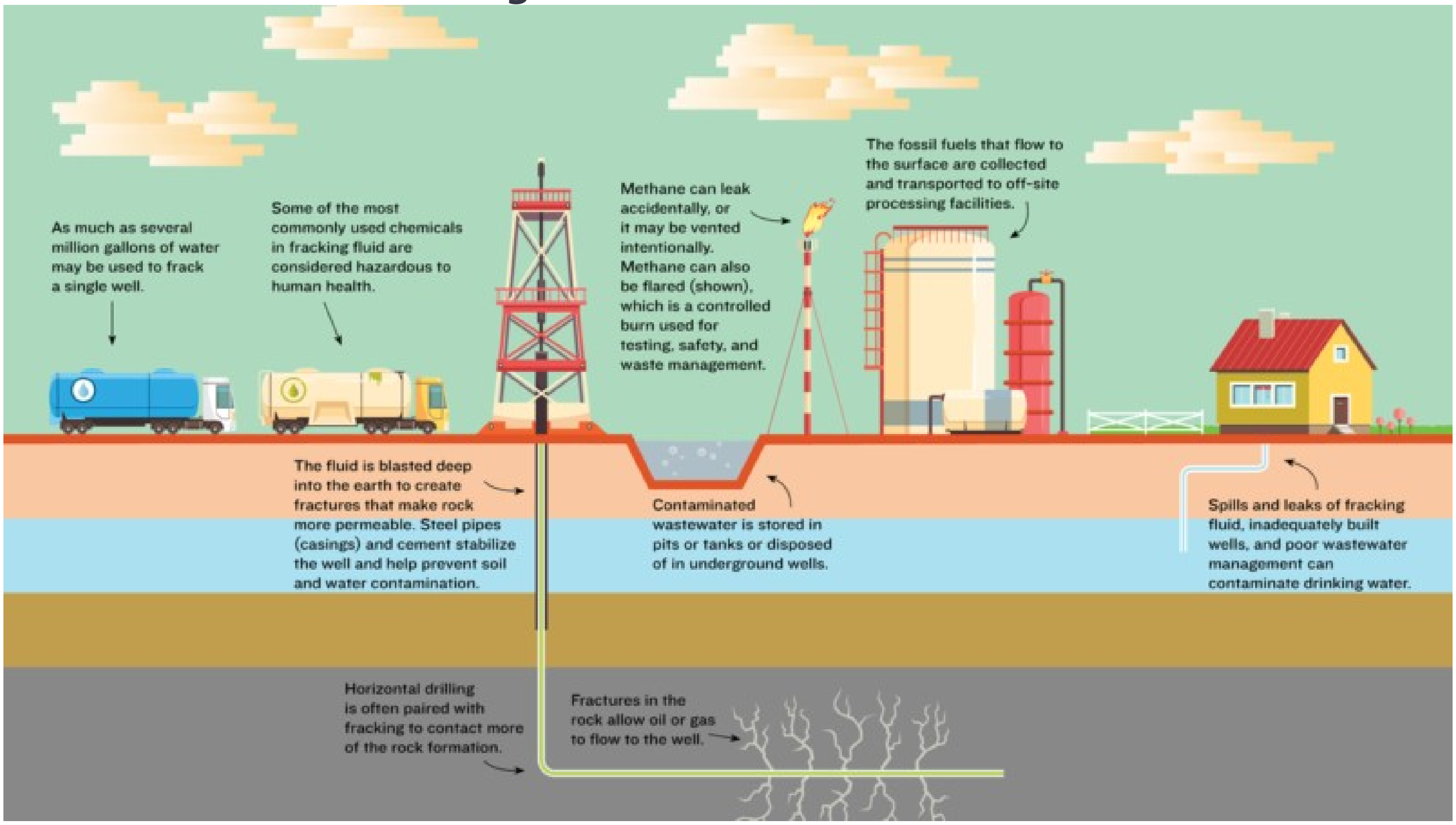
Rods after buckling.



5) <u>Sand production :</u> If there is sand on the oil bed and we pump fast , this results in sand particles getting stuck between the valves and the other equipment, sand moving at high speed is abrasive because of the Sandblasting effect.

Wear of Plunger caused by sand production

Issues with fracking :



https://www.thesciencethinkers.com/what-is-fracking-facts-about-fracking/

What is fracking? (https://www.bbc.com/news/uk-14432401)

Fracking is the process of drilling down into the earth before a high-pressure water mixture is directed at the rock to release the gas inside.

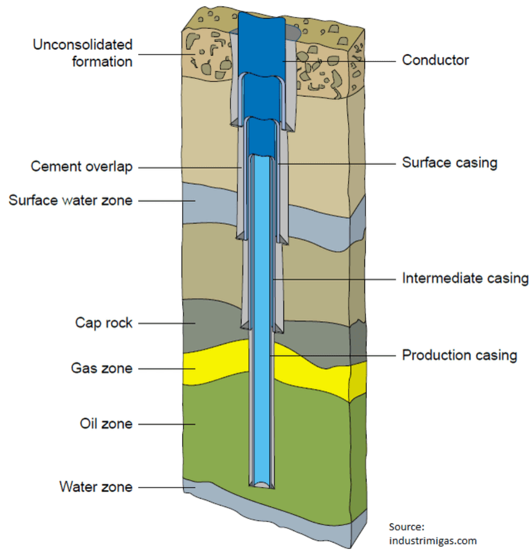
Water, sand and chemicals are injected into the rock at high pressure which creates cracks from which the trapped or any remaining gas will flow out to the head of the well.

The chemicals create gas that breaks the rocks with high pressured water. The sand gets in between the gaps and does not let it close. From the cracks the gas or oil flow out to replenish the oil well.

Assumption : Fracking is done when we observe that the well production oil flow is low. As our case study is of a Stripper Well, chance is that Fracking has already been attempted in these wells.

Why so much water ?

We know that water is heavier than oil and oil is heavier than gas. So by replacing with high pressured water the top layer that is gas will rise up to the well followed by oil and then followed by the water.



The process can be carried out vertically or, more commonly, by drilling horizontally to the rock layer, which can create new pathways to release gas or used to extend existing channels.

The term fracking refers to how the rock is fractured apart by the high-pressure mixture.

Issues with Fracking :

1) Fracking uses huge amounts of water, which must be transported to the site at significant environmental cost.

2) As well as earth tremor concerns, environmentalists say potentially carcinogenic chemicals or even radioactive chemicals may escape during drilling and contaminate groundwater around the fracking site.Injection of radioactive tracers along with the fracturing fluid is sometimes used to determine the injection profile and location of created fractures.Fracking releases naturally occurring heavy metals and radioactive materials from shale deposits, and these substances return to the

surface with flowback, also referred to as wastewater. Possibilities of lung cancer, damage to the thyroid,thyroid cancer in later life just by mistakenly drinking or unknowingly using this water.

3) Campaigners say fracking is distracting energy firms and governments from investing in renewable sources of energy, and encouraging continued reliance on fossil fuels.

4) The water used after fracking may not be be recyclable as there are toxic and radioactive elements along with oil particles and gas. So that water literally needs to be dumped. If dumped under ground we never know which under ground water sources it might pollute and when.

5) It weakens the below surface structures so landfalls may occur causing damage to the property.

6) Release of Methane is a huge problem here as it is a major Greenouse gas.For example, a report by Environmental Defense Fund (EDF) highlights this issue, focusing on the leakage rate in Pennsylvania during extensive testing and analysis was found to be approximately 10%, or over five times the reported figures.

7) Increases in seismic activity and sink hole formation following Fracking along dormant or previously unknown faults are sometimes caused by the deep-injection disposal of Fracking flow back (a byproduct of hydraulically fractured wells).

Sensors for measuring oil well equipments :

https://sensing.honeywell.com/honeywell-sensors-switches-oil-rig-application-note-000756-4-en.pdf

Observe that majority of the sensors are present for surface equipment.

Let’s checkout the available few sensors for downhole equipment monitoring.

1) Pressure transducer and transmitter: For pressure measurement.A pressure sensor works by converting pressure into an analogue electrical signal. Transducer converts the pressure into electicl signals like volt milli volt and milli ampere. Transmitter converts it. Pressure = force/area

Units

Pa - [Pascal] in 1 Pa = 1(N/m²)
Bar

PSI => Pressure per square inch.

2) Load cell : Converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured and standardized.

3) Torque Sensor : Torque is defined as a twisting force that tends to cause rotation. Dynamic Torque involves acceleration. Torque sensor is a device for measuring and recording the torque on a rotating system, such as an engine, crankshaft, gearbox, transmission, rotor, a bicycle crank , etc . Example of non-contact sensors : magnetoelastic torque sensors.

4) Flow Meter : A device installed in a pump manifold or treating line to measure the fluid flow rate. It can measure both oil or gas. It can be installed in the pump or pipeline.

5) Temparature sensor : Distributed Pressure and Temperature Sensing System, or DPTS, is a novel, low-cost technology solution for permanent, downhole pressure and temperature measurements in the oil & gas industry.

6) Corrosion sensor : The multielectrode array sensor (MAS) probe is ideally suited for monitoring corrosion rates in process streams. The MAS probe measures corrosion rates by assessing the current flow between coupled electrodes.

The Pulsed Eddy Current method is another inspection technique used to detect corrosion under insulation. Eddy currents are generated in the pipeline wall due to magnetic field produced by a coil. The coil-induced magnetic field is created by applying and controlling the electrical current to the coil. The thicker the pipeline wall, the longer it takes for the eddy currents to decay to zero. This property and technique are used to detect remaining wall thickness of pipelines.

7) Seismographic sensors : Geophones : The source generated signal at the vibrator is used to create the seismic wavelet. The seismic waves that travel from the source into the earth are received on geophone sensors planted on the surface at different offsets or incremental distances away from the source point.

8) Hydrocarbon sensors : For oil monitoring and mapping applications, a crude oil sensor with a near UV LED source and a refined fuels sensor are useful. The crude oil sensor can detect oil throughout the water column in offshore monitoring.

9) Oil leak detection sensor : Ultra Sonic leak detector (ULD) is used to detect a wide variety of leak scenarios in wells all over the world.It takes advantage of the unique properties of ultrasound energy propagation through various media. The movement of fluids across a failed barrier creates turbulence which in turn creates ultrasonic frequency sound waves that are detected by the tool sensor. This new tool is different from the conventional noise logs as its' highly customized multiple sensitivities enable the detection of leaks as small as 0.02 Litres per Minute (LPM) with an accuracy of inches in the production tubing, casing and other completion equipment. It is also practically immune to disturbances from distant noise sources.

First Cut Approach

The dataset given consists of downhole well failures in the equipment marked with target 1 and surface related failures with target value of 0.

0 59000 ==> Surface related failures
1 1000 ==> Downhole well failures

1) Get an idea as to the readings could be from what all sensors.
2) Start the basic EDA .
3) Try to figure out if sensors have NaN values in both the target values or unique to one target value only.
4) Try to figure out why there are NaN values when there could have been their respective default values. What is the meaning of NaN values in this case ?
5) Figure out if I should replace the NaN values with 0 or average or a value similar to the same target value or should I simply ignore the data points with NaN value.
6) Find the duplicates . Duplicate data points are of no value.
7) Find the mean /median/mode 25-50-75 percentiles.
8) Normalise the features.
9) Try spearman corelation coefficient to find out co relation. (It is good for cause and affect analysis but it might not be of much use when we find that our features are dependent on other features, we expect our features to be independent of each other.).

10) Try and plot it's histogram for both the target values.
11) Try box plot / voilin plot to visualize the outliers.
12) Perform PCA find which feature gives the highest variance . Try the same with tSNE.
13) The data set is highly imbalanced , and all the features are numerical so I will try Smote, BorderLineSmote, Adasyn,
OneSidedSelection (undersampling).
Smoteen or SmoteTomek etc for the combination of over sampling and undersampling.
14) After this I will give the data to my ML Algorithms / DL Algorithms.

Reference Links :

Dataset : https://www.kaggle.com/c/equipfails/
Research paper :
https://www.researchgate.net/publication/321137529_Failure_analysis_of_the_offshore_process_component_considering_causation_dependence
https://www.quora.com/profile/Fred-Feinberg
https://drillers.com/what-is-a-stripper-well/
https://en.wikipedia.org/wiki/Plunger_pump
https://production-technology.org/beam-pumping-unit/
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https://www.bandaslawfirm.com/personal-injury/work-injuries/oil-accidents/equipment-failure/