NOGEPA
NETHERLANDS OIL AND GAS EXPLORATION
AND PRODUCTION ASSOCIATION

# INDUSTRY STANDARD
# NO. 50

# Kick Tolerances for Well Design and Drilling Operations

**09 December 2020**

# Index

# Document Control Sheet

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This document will be controlled in accordance with the NOGEPA Industry Standard No. 80 on Standards and Document Control.

## Terms and definitions

| | |
|---|---|
| A-annulus | means the annulus between the drill pipe, production or testing tubing and the production casing. |
| Competency | Means ability of an individual to do a job properly through a combination of training, demonstrated skills and accumulated experience. |
| Handover | means act or process of transferring responsibility for operating a well from one competent party to another, including both custody to operate (certificate) and the requisite data and documents which describe the well construction. |
| HPHT Well | means a well with an expected pore pressure exceeding a hydrostatic gradient of 0.8 psi/ft (1.85SG) or requiring pressure control equipment >10.000 psi and with a static BHT >149°C (300°F) |
| Kick Tolerance | See chapter 3.1 |
| MAASP | means the greatest pressure that an annulus can contain, as measured at the wellhead, without compromising the integrity of any element of that annulus, including any exposed open-hole formations. |
| Management of Change | a best practice that controls safety, health, and environmental risks and hazards as they pertain to an organization's changes to its facilities, operations, or personnel. |
| Off-set Wells | means existing wells, either producing or de-commissioned in the area, the data package of which serve to arrive at an optimum well design. |
| Pore Pressure | means the pressure of a fluid in a permeable formation. |
| Reservoir | means the porous and permeable formation which contains hydrocarbons or water. |
| Risk Assessment | means the systematic analysis of the risks from activities and a rational evaluation of their significance by comparison against predetermined standards, target risk levels or other risk criteria. |
| SECE: Safety and environmental critical element | means part of the installation or plant that is essential to maintain the safety and integrity of the installation. |
| Surface Casing | means the casing which allows first installation of the BOP stack. |
| (drilling) Kick | Means an influx that has been caused by insufficient mud weight to control the reservoir during drilling activities. |
| Swab Kick | Means an influx that has been caused by the dynamic effects of well equipment during tripping activities. |
| Well Integrity | means the application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids and well fluids throughout the life cycle of a well. |

## Abbreviations

| | |
|---|---|
| API | American Petroleum Institute |
| BHA | Bottom Hole Assembly |
| BHP | Bottom Hole Pressure |
| BHT | Bottom Hole Temperature |
| BOP | Blow Out Preventer |
| CSIP | Casing Shut In Pressure |
| ECD | Equivalent Circulating Density |
| FBG | Formation Break-down Gradient |
| FG | Fracture Gradient |
| FIT | Formation Integrity Test, which includes Limit Test (LT) |
| FS | Formation Strength |
| HPHT | High Pressure High Temperature |
| IADC | International Association of Drilling Contractors |
| ID | Internal Diameter |
| LCM | Lost Circulation Material |
| LOT | Leak Off Test |
| MAASP | Maximum Allowable Annulus Surface Pressure |
| MD | Measured Depth Along Hole |
| MOC | Management of Change |
| MPD | Managed Pressure Drilling |
| MW | Mud weight |
| OBM | Oil Based Mud |
| OD | Outside Diameter |
| PWD | Pressure While Drilling |
| SICP | Shut In Casing Pressure |
| SodM | Staatstoezicht op de Mijnen (State Supervision of Mines) |
| TD | Total Depth |
| TVD | True Vertical Depth |
| WHP | Well Head Pressure |

## Legal Requirements

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|---|---|
| Offshore Safety Directive | EU Directive 2013/30/EU |
| Mining Decree | The current decree section 5.3 incorporates articles relating to "Boorgaten".<br>Of critical importance are 3 goal setting articles (67, 68 and 69) providing instructions to prevent damage and the obligation to control subsurface fluids. |
| Article 67 | 1. When constructing, using, maintaining, repairing and decommissioning a borehole, measures shall be taken to prevent damage.<br>2. The construction, maintenance, repair and decommissioning of a borehole shall take place under the responsibility and in the presence of the operator. The use of the borehole shall take place under responsibility of the operator. |
| Article 68 | The activities as meant in Article 67.1 shall only be performed if the substances in question from subsoil formations can be maintained under control. |
| Article 69 | 1. A borehole shall be fitted with suitable tubing.<br>2. Each series of tubing as referred to in Article 69.1 shall be cemented over a sufficient distance and then tested for reliability.<br>3. The first series of tubing shall be properly sealed immediately after it has been properly cemented. |
| Mining Regulation | Chapter 8.2.1.1 8.2.1.1.1 8.2.1.1.2 8.2.1.2<br>8.2.2.1 8.2.3.2 8.3.3.2<br>8.3.4.1 8.4.1. 8.4.3 |

## Related Documents

| | |
|---|---|
| API RP49 | Drilling & Well Servicing operations involving $H_2S$ |
| API 5C2 | Performance properties of casing, tubing and drill pipe |
| API 5CT | Casing and tubing connections |
| API 6A | Wellhead and X-mas tree equipment |
| API 14C | Surface safety systems for offshore platforms |
| API 16A | Drill through equipment |

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| API S53 | BOP equipment systems |
| API RP64 | Diverter systems |

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|---|---|
| ISO 10407 – 1993 | Drill stem design & operating limits |
| ISO 10423 – 2009 | Wellhead & X-mas tree equipment |
| ISO 10426 | Cement & materials for well cementing |
| ISO 11960 - 2014 | Casing, tubing & pup joints |
| ISO 13628 | Design & operation of subsea wells |
| ISO 16530-1 | Well Integrity Life Cycle Governance |
| ISO 16530-2 | Well Integrity for the Operational Phase |

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|---|---|
| NOGEPA Industry Standard 1 | Training |
| NOGEPA Industry Standard 4 | Competency |
| NOGEPA Industry Standard 41 | Well Engineering and Construction Process |
| NOGEPA Industry Standard 42 | Well Examination |
| NOGEPA Industry Standard 43 | Surface BOP |
| NOGEPA Industry Standard 44 | Standards & Acceptance Checklist |
| NOGEPA Industry Standard 45 | Well Decommissioning/Het buiten gebruikstellen van putten |
| NOGEPA Industry Standard 46 | Well Integrity Management |
| NOGEPA Industry Standard 48 | Independent Verification Management |
| NOGEPA Industry Standard 50 | Kick Tolerance |
| NOGEPA Industry Standard 51 | Operational Barriers for Well Integrity |
| NOGEPA Industry Standard 80 | Standards and document control |

## Important Nomenclature used in this Standard

| In the context of this Standard and when so used to describe a method or practice: | |
|---|---|
| 'shall' | means that such method or practice reflects a mandatory provision of law (in Dutch: *dwingend recht*). Such method or practice is mandatory for those who are the addressees of such provision (mostly the operators). A Standard can describe or quote, but not amend, mandatory provisions. When an operator in exceptional cases for technical, operational or HSE reasons cannot comply, exceptions shall be documented and reported, and risks mitigated. Please note that this does not release the operator from the obligation to comply with the law. * |
| 'should' | means that such method or practice reflects a Good Operating Practice. An operator is generally expected to apply such method or practice, but a specific situation may require a specific alternative. In other words: the operator complies or explains, and documents the explanation. * |
| 'could' | means that such method or practice is of an advisory nature or mentioned by way of example. An operator is not obliged to comply and is not obliged to explain if he does not comply. |
| * Please refer to paragraph 2.3 of Standard 80 (Standards and Document Control), for further explanation on an exception of a 'shall' provision, or on a comply-or-explain of a 'should' provision. | |

# 1. Executive Summary

This Standard gives guidance to address adequate kick tolerance requirements for all Operators active in the Netherlands and on the Dutch Continental Shelf. Risk Assessment is an important tool to establish adequate kick tolerances when designing and drilling a well and for assessing whether additional mitigating measures or contingencies have to be planned and executed.

Correctly calculating and understanding kick tolerance is essential to safe well design and drilling the well.

There are numerous Standards and Guidelines related to drilling processes. These describe best practices and recommendations in detail. However, even though kick tolerance is a critical and fundamental concept for the drilling industry, no uniformity is found between the various operators and drilling contractors and neither the API nor the IADC seem to provide a standard method.

Relaxed kick tolerances may lead to unacceptable levels of risks and unnecessary well problems.

When kick tolerances are set too conservatively, this will lead to increased costs, due to an over-engineered well design. The consequence may be that some wells will not be technically feasible.

The aim of this Standard is not to set upfront arbitrary volumes as a minimum for kick volume.

For each well the calculations must be made, based upon pore pressure, fracture gradients and well architecture.

The ultimate goal is to have a Standard that will be used by engineers at the office during the well-planning stage, as well on rig site by drilling supervisors, to offer a clear and direct evaluation of the conditions of the well, allowing safe continuation of the drilling operations.

Also important when defining kick tolerances are:

- Clear instructions on rig site.
- Competence, communication and team work in place.
- Calibrated dual pit level and trip-tank measurement system.
- Adequate BOP and BOP control system.
- Third party monitoring of well and measurement (MPD, Mud Logging Services etc.)

Given the international nature of our industry imperial units have been used.

# 2. Scope and application

## 2.1 Scope

The purpose of this Standard, hereinafter referred to as ”Standard”, is to provide guidance to establish adequate kick tolerances, for use by Exploration & Production (E&P), companies, when designing programs for drilling exploration or development wells.

The scope of this Standard is restricted to:

- The Netherlands and the Dutch Continental Shelf;
- Drilling Exploration, Appraisal and Development wells; and
- Sidetracks or deepening of existing wells.

## 2.2 Application

This Standard **should** be applied for setting kick tolerances when designing and drilling for wells for E&P companies.

It is noted that HPHT and MPD wells may require a higher level of attention to a wider range of potential risk scenarios.

# 3. Kick Tolerance

## 3.1 Definition

Kick Tolerance is an important factor in the industry, that allows drilling engineers to establish several parameters in the design and execution phase of a well, such as casing depths, open hole lengths, well control safety margins, etc. It can also be considered a valuable safety factor to prevent well control problems. Several different definitions and calculation approaches can be found for this term.

For practical purposes, kick tolerance may be defined as the maximum kick volume on bottom which can be tolerated without fracturing the weakest zone in the wellbore, normally assumed to be at the last casing shoe.

## 3.2 Calculating Kick Tolerance while planning

The amount of influx volume that enters the well depends on:

- underbalance between mud weight and pore pressure.
- reservoir porosity and permeability.
- influx type and density.
- sensitivity and reliability of detection equipment.
- reaction time of well control crew.
- type well shut in procedure.
- time of BOP closure.
- drilling fluid type
- hole volume

It must be understood that the calculated kick tolerance for a well design is usually based on more or less accurate assumptions of formation strength, pore pressure and other parameters.

For the purpose of well design and monitoring of wells with potential kick capability, kick tolerance should be calculated in terms of kick volume which can be circulated out without fracturing the weakest zone in the wellbore, normally assumed to be at the last casing shoe. Such calculation should not be oversimplified and as a minimum be in line with current industry practice calculation methods such as the formula below, where the effects of T (temperature) and Z (compressibility) are ignored.

When calculating kick tolerance we differentiate between two scenarios:

i. Drilling kick
ii. Swab kick

Assumptions for Kick Tolerance calculation shown on the next page:

- vertical well (yet this does not only apply to vertical wells).
- single mono phase gas bubble.
- two drill string diameters (BHA & DP).
- one open hole size.
- constant ECD profile.

The following has been neglected:

- gas velocity and its real distribution in the annulus.
- P & T influence on mud weight and influx gradient.
- gas composition, dispersion and solubility.
- Any frictional pressure loss effects. The calculation is based on static conditions

### i. Drilling Kicks

When the top of the gas bubble reaches the shoe while being circulated using the Driller's method, the pressure at the casing shoe is given by:

$$P_x = P_f - P_g - (Z_{OH} - H - Z_{CSG}) \times G_{mud}$$

where

$P_x$ = Pressure at the casing shoe, psi

$P_f$ = Formation pressure at section TD, psi

$P_g$ = Hydrostatic head of gas bubble (H x $G_{gas}$), psi

H = Height of gas bubble at casing shoe, ft

$G_{gas}$ = Gradient of gas (0.05 to 0.15), psi/ft

$G_{mud}$ = Maximum gradient of mud (Maximum mud weight, ppg x 0.052), psi/ft

$Z_{OH}$ = Vertical depth of open hole at section TD, ft

$Z_{CSG}$ = Vertical depth of casing shoe, ft

Re-arranging the above equation in terms of H and replacing $P_x$ by the fracture pressure at the shoe ($P_{frac}$) gives:

$$H = \frac{P_f - (Z_{OH} - Z_{CSG}) \times G_{mud} - P_{frac}}{(G_{gas} - G_{mud})}$$

where

$P_f$ = Formation pressure at section TD, psi

$Z_{OH}$ = Vertical depth of open hole at section TD, ft

$Z_{CSG}$ = Vertical depth of casing shoe, ft

$G_{mud}$ = Maximum gradient of mud (Maximum mud weight, ppg x 0.052), psi/ft

$P_{frac}$ = Fracture pressure at casing shoe (= $LOT_{ppg} \times Z_{CSG} \times 0.052$), psi

$G_{gas}$ = Gradient of gas (0.05 to 0.15), psi/ft

The volume of the (gas) influx at the casing shoe is

$$V_1 = H \times CAP_{ann}$$

where

H = Height of gas bubble at casing shoe, ft

$CAP_{ann}$ = Volumetric capacity of the annulus between pipe and hole, bbl/ft

At bottom hole conditions the equivalent volume of the (gas) influx is given by:$P_2 \times V_2 = P_1 \times V_1$

where

$P_1$ = Fracture pressure at casing shoe (= $LOT_{ppg} \times Z_{CSG} \times 0.052$), psi

$V_1$ = The volume of the (gas) influx at the casing shoe, bbl

$P_2$ = Formation pressure at section TD, psi

$$V_2 = \frac{P_1 \times V_1}{V_2}$$

The value of $V_2$ is the kick tolerance in bbls.

With other words: Kick tolerance can be explained as follows:

- Kick tolerance is the maximum vertical height of a gas influx column that the open hole section can tolerate. This height is converted into a volume, considering the geometry of the hole minus the geometry of the drill string. This is the largest volume of influx that can be safely removed from the well.

These formulas in either direction are incorporated in several available software or Excel spreadsheets. With reference to the documents mentioned in section 1 and software documentation (Schlumberger, Landmark, etc.) the individual parameters will not be explained further. It should be noted that Landmark is applying temperarture and Z-factor in their calculations.

During well planning the required FIT value can be determined based on the minimum required kick tolerance volumes.

The following minimum kick tolerance volumes are a guide to calculate the required FIT as a first iteration and subject to the input parameters for the well to be designed:

- 50 Bbls for all hole sizes of 16” or greater.
- 25 Bbls for hole sizes in between 16” and 8-1/2”.
- 13 Bbls for hole sizes of 8-1/2” and less.

These volumes are based on the industry practice of the open hole volume of 2 stands of triple drill pipe, which are considered to provide sufficient margin to detect a kick and safely close in the well (i.e. the influx volume not exceeding the KT volume). Detectable volume should not be confused with the KT volume (i.e. the maximum allowable influx volume that can still be circulated out safely without fracturing the weak point).

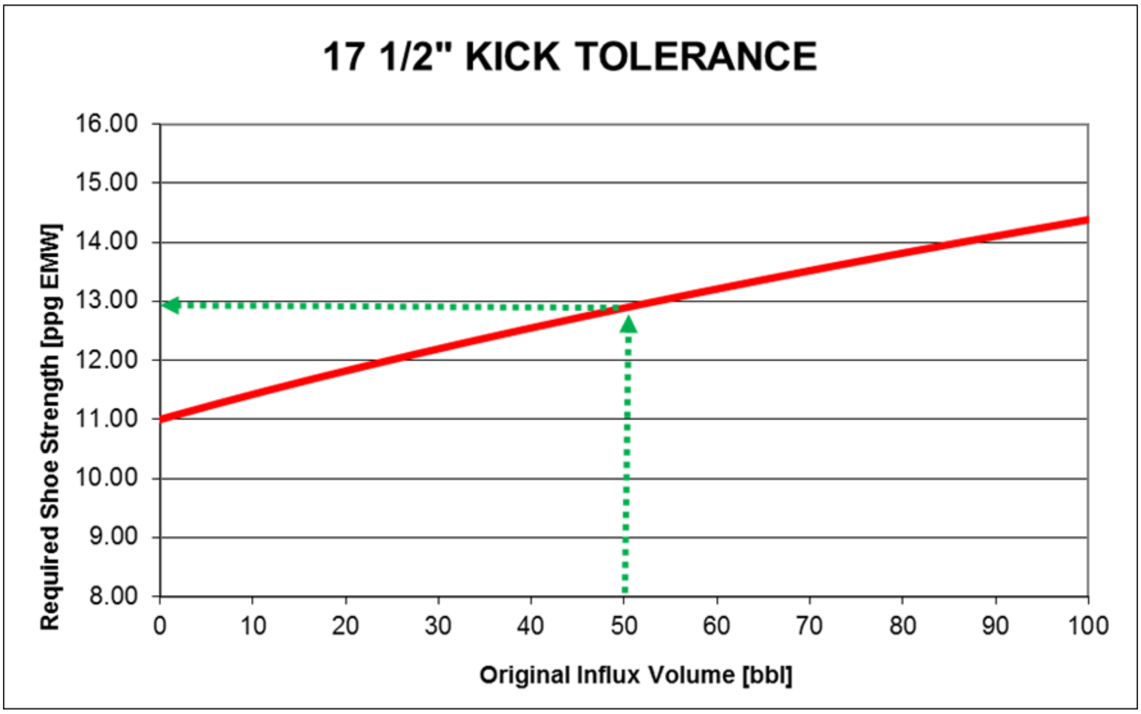
These volumes do not address the difference between swab kicks and kicks while drilling.

The standard kick intensity is usually 0.5 ppg in addition to the maximum anticipated formation pressure.

For any resulting value lower than the kick tolerance volumes suggested above a risk assessment should be done, to assess whether potential outcomes of kicks stay within acceptable consequence levels.

This risk assessment should distinguish between swab kicks and kicks while drilling and address the different surface set up, detection system and alarm setting during tripping and drilling

The risk assessment should also include amongst others an assessment of the feasibility of being able to detect the smaller influx volume (considering accuracy and reliability of the kick detection system), crew response time. The risk assessment of lower kick tolerance volumes could also include sensitivity checks on uncertainties such as pore pressure prediction, formation strength, formations tops, etc. The risk assessment could include an assessment of possible mitigations (e.g. pumping out of hole to reduce the risk of swabbing); or whether an additional casing point could be required in the well design.



This picture shows that in order to achieve a kick tolerance of 50 bbls, the formation strength the weakest zone in the wellbore, normally assumed to be at the corresponding previous casing shoe needs to be 13.0 ppg

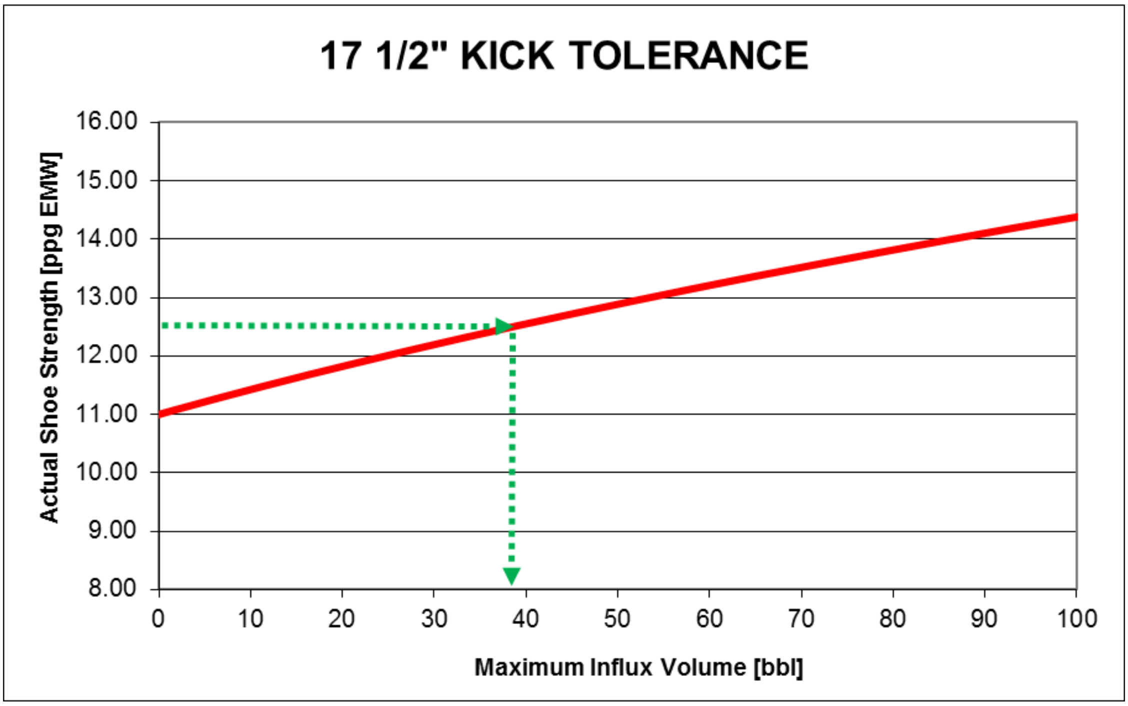
### 3.3 Adjusting Kick Tolerance during drilling

While drilling, the actual kick tolerance should be recalculated as soon as more accurate information is available. Such as:

- LOT (leak off test) or FIT result.
- Actual mud density.
- Actual formation strength in the well bore
- Actual pore pressure data

Once the actual kick tolerance has been evaluated it needs to be compared with the calculated values during well planning. If the kick tolerance is smaller than the values documented in the drilling program the rig needs to be informed about the changes by means of the MOC procedure of the individual Operator. Additional measures (training, equipment, supervision) might be required to proceed operations with the smaller numbers. These measures should be mentioned in the MOC.

Since rig equipment is known and crew competency evaluated the minimum values can be risk assessed and validated.



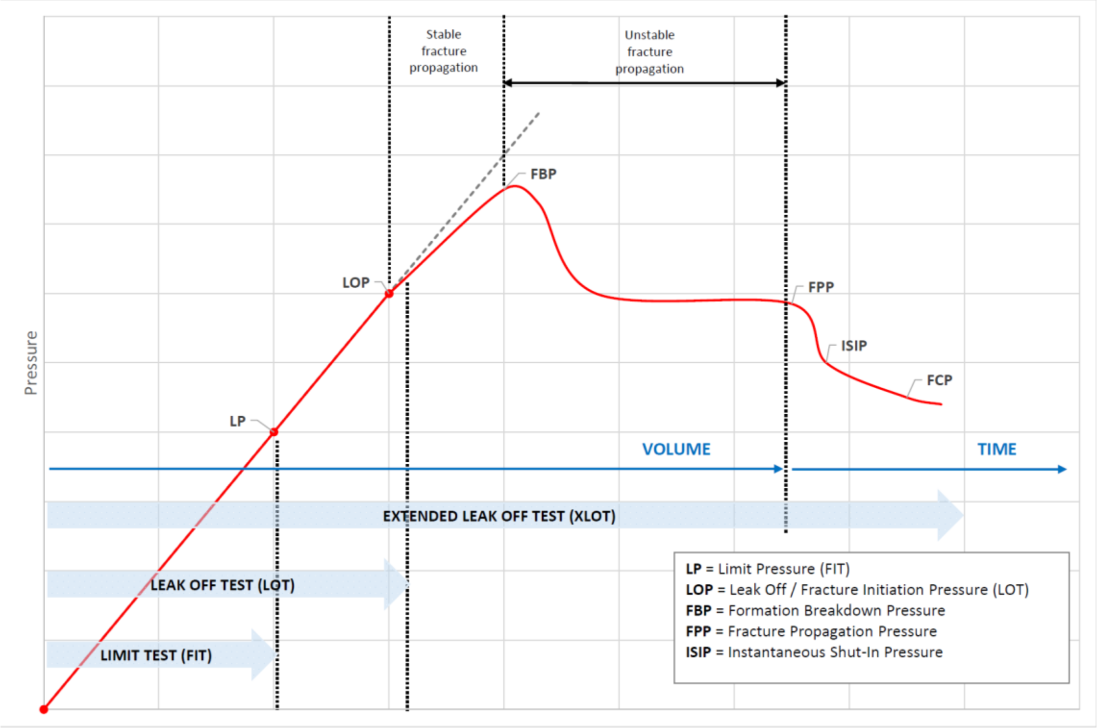
For a given formation strength of the weakest zone in the wellbore, normally assumed to be at the corresponding previous casing shoe 12.5 ppg, the kick tolerance is 39 bbls

# 4. Formation Evaluation

## 4.1 Fracture Gradient Determination

Referring to below listed graph, we can distinguish three different kind of formation strength tests:

- FIT: Formation Integrity Test (or LT: Limit Test). A test carried out to a specified value, always planned below the fracture gradient of the formation.
- LOT: Leak off Test. A test carried out to the point where the formation shows the very first signs of leaking off (Fracture Initiation Pressure). Then pumping is stopped immediately.
- Formation Breakdown Test. A test carried out to the Formation Breakdown Pressure and beyond



## 4.2 Formation Integrity Test or Limit Test

The main reasons for performing an FIT are:

- To investigate if the strength at the casing shoe is sufficient to cover all load cases identified to drill the next hole section.
- To investigate the strength of the cement bond around the casing shoe and to ensure that no communication is established with higher strata.

After having drilled out the shoe track of the casing plus a few more meters of fresh formation, the well will be circulated until a homogenous mud is in the well. With the drill bit pulled back inside the casing shoe, the BOP will be closed and a pressure test to a previously calculated value will be carried out on the well, to verify that the shoe strength is as per the rock strength assumptions of the drilling program. The pressure test can be done while continuously pumping to the desired value, or in steps. The latter option could be chosen in case there is doubt that the required pressure will be achieved

## 4.3 Leak-off Test

The main reasons for performing a LOT are:

- To determine the maximum kick tolerance
- To collect regional information on the formation strength for optimization of well design for future wells.

## 4.4 Formation Breakdown Gradient

Knowledge of the formation breakdown gradient (FBG) could be of importance to obtain data for optimizing the design of future development wells. Determining of this pressure leads to permanently weakening of the formation. Therefore, the formation breakdown pressure should not be used to calculate the kick tolerance in the design or actual drilling of a well

# 5. Additional Factors affecting Kick Tolerance

## 5.1 Choke Line Friction or long & slim hole annulus

The exposed formations beneath a casing string shall have sufficient strength to withstand the drilling loads that will be applied to them. The loads that will be applied include the hydrostatic pressure of the fluid column (static pressure), additional frictional pressure applied whilst circulating (equivalent circulating density or ECD) and the pressures that would be applied if an influx was taken into the wellbore. In most circumstances the kick tolerance calculation will be the defining force with respect to formation strength requirements, but equivalent circulating densities should also be considered, as they can be significant in slim hole sizes or where long choke lines are in use.

## 5.2 Losses during drilling

Losses during drilling a hole section indicate a formation, which has a lower breakdown gradient than the formation in which the last casing has been installed and cemented into.

The formation strength at the last casing shoe remains valid as tested. However, the formation taking fluids might not provide sufficient integrity to drill deeper formation with higher pressure and mobile content.

In case formations with different pressure regime than the one taking losses need to be drilled to section TD several measures could be considered to provide kick tolerance in line with the kick tolerance at the casing shoe, such as:

- Open hole FIT, recalculate kick tolerance and assess whether drilling can continue safely or whether a design change is required (examples mentioned below)
- Intermediate casing/liner.
- Adjust TD.
- Plug back & re-drill.
- Cement squeeze or stress caging.

## 5.3 Choke Operator/Driller Errors

During well control operations good communication is essential between the choke operator and the driller who controls the mud pump.

To allow for errors whilst operating the choke, a safety margin is applied by subtracting pressure from the leak off pressure at the weak point.

## 5.4 Errors in Kick Density, Compressibility factor Z and Temperature

### 5.4.1 Kick Density

The application of generalized gas gradients may lead to errors in the kick tolerance calculations. It is recommended to use actual gas gradients based on pressure and gas composition to make the kick tolerance calculation more robust

### 5.4.2 Z factor

The industry uses Z=1 (considering the influx an ideal gas) for calculations. This is an acceptable way, since the errors will affect the result only marginally. No safety factor required. For significant high pressure or HPHT wells it is recommended to review the impact of the Z-factor on kick tolerance, since the Z-factor might be significantly higher than 1.

### 5.4.3 Temperature

The simplified method that is in use assumes that the influx temperature is constant. But while it moves up the hole, temperature will reduce, therefore our calculations can be considered conservative again. No safety factor is required.

## 5.5 Solubility of influx into the oil Base Drilling Fluid

The solubility of gas, CO2 and H2S in OBM are an additional risk to any drilling plan. All these gases can dissolve into the oil phase of the drilling fluid. Especially with higher pressures, solubility may cause an influx to become problematic due to rapid expansion at shallower depths. It is therefore recommended to perform more detailed calculation (using Z factor or multi-phase) in such situations.

## 5.6 Other Factors

Parameters that affect the severity of a well control incident are amongst others:

- Swabbing
- BHA length, geometry & annular capacities
- Influx density
- Single bubble
- Presence of H2S & CO2
- Weakest point other than casing shoe
- Mud rheology
- Dispersion
- Fluid Migration
- Influx mobility
- Porosity and permeability
- Human, organisational and hardware factors