Introduction

In the first edition of API 682 (1994), limited information was given about the pressurized seal barrier systems. The plans 53 and 54 were mentioned but the information of a plan 53 was only with use of a reservoir.

Difference between the design options for plan 53 seal barrier systems was first made with the release of the second edition of the standard in 2002. It was in this edition that the letters A, B and C were introduced and added to plan 53. Plan 53A was assigned to systems using a reservoir, plan 53B to systems using a bladder accumulator and plan 53C to systems using a piston accumulator.

In the fourth edition of API 682 (2014), the description, use and calculations (tutorial) of 53 systems are described in more detail. Specifically, the information about plan 53B systems often result into confusion and miscommunication between end users/contractors and mechanical seal manufactures.

The information in this document is intended to give guidance on the selection of plan 53B systems and the use of bladder accumulators. Differences, pros and cons between the two alarm strategies are discussed and options provided on improvements.

API plan 53B system

An API plan 53B system (Figure 2) is a pressurized barrier liquid system connected to a closed barrier loop circuit. This barrier loop is connected to the in- and outlet connection of an arrangement 3 pusher or non-pusher (e.g. bellows) seal. A pumping feature, integrated in the mechanical seal design, or circulating pump, is forcing the barrier liquid to flow through the barrier loop. For temperature control, a heat exchanger (liquid or air cooled) is installed in the barrier loop. This heat exchanger is dissipating the heat generated by the mechanical seal and, for high temperature applications, the heat flux from the process fluid into the barrier liquid. Heat exchangers are installed elevated above the seal cartridge to promote thermo-syphoning in standby condition.

Liquid is a non-compressible medium which can't store any energy. This means that every drop of leakage will result in a large pressure drop in the closed loop barrier system. To prevent this, a gas (generally nitrogen) which can store energy, is used to pressurize the barrier loop, preventing large pressure drops from leakage of barrier liquid from the system.

The difference between a plan 53B (Figure 2) with a plan 53A (Figure 1) is that the pressurizing gas in a plan 53B utilizes a bladder accumulator so that the pressurized gas will not be in direct contact with the barrier liquid. This prevents gas solubility into the barrier liquid and makes plan 53B systems suitable for high pressure applications.

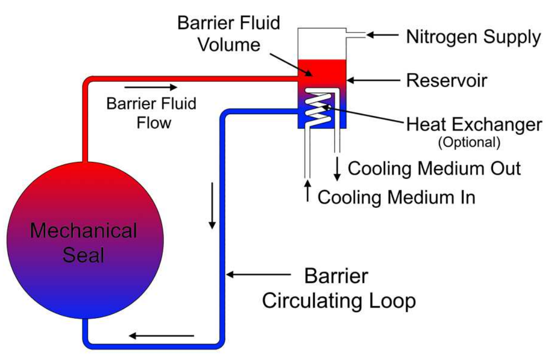


Figure 1: API plan 53A

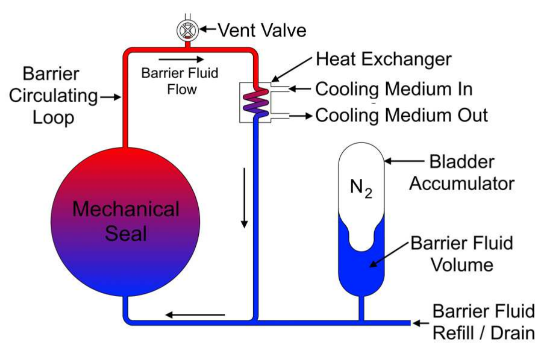


Figure 2: API plan 53B

Good practice is to place the bladder accumulator in the refill line and out of the barrier loop so that the nitrogen inside the bladder is not affected by the barrier temperature. To further reduce the effect of the barrier temperature on the nitrogen, the refill line is connected to the barrier loop in the line from the heat exchanger to the seal cartridge.

Prior to filling the barrier loop with liquid, the bladder, inside of the accumulator, is filled and pressurized with a gas to a pressure just below minimum barrier liquid pressure (gas pre-charge pressure). API 682 advices a minimum working volume of 1% of the total accumulator volume which results in a pre-charge pressure of 99% of the minimum barrier pressure. This can be risky for low pressure applications. For example, the gas in the accumulator for an application with a minimum barrier pressure of 10 bar, must be pre-charged at minimum ambient temperature, to a pressure of 9.9 bar. Due to the small difference between minimum barrier pressure and pre-charge pressure and inaccuracy of the used pressure indicator, it may be that the nitrogen is pre-charged to just above 10 bar which leads to an empty accumulator before the alarm pressure is reached. To prevent this, it is a recommended practice to increase the minimum volume to 10% of the total accumulator volume.

Once pressurized, the gas inside the bladder is isolated with a valve and gas supply disconnected. The barrier loop system will then be filled with a barrier liquid using a pump. When the barrier liquid pressure reaches the gas pressure inside the bladder, the bladder will be compressed. The gas inside the bladder is following the combined gas law ($\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} = C$) which means that the gas volume inside the bladder will decrease while the pressure of both gas and barrier liquid, will increase till the desired barrier pressure is reached.

Ambient temperature fluctuations will influence the gas temperature and consequently the pressure in the barrier liquid system. Without leakage from mechanical seal and/or system, the volume of the barrier liquid and thus gas volume, will not change. This means that the gas temperature only influences the pressure in the system. A lower gas temperature will reduce the pressure where a higher gas temperature increases the pressure in the barrier system. Both situations may be of risk as a lower pressure, due to a low temperature, may cause an early alarm and fail to meet the required refill period where a higher pressure may exceed the mechanical seal and seal support system MAWP.

Leakage in- and refill of the system will have influence on both pressure and volume.

Plan 53B systems are equipped with an alarm set point used as a refill alert for the barrier system. Based on the selected strategy, the alarm can be based on a fixed or floating pressure. For extra safety a low-low alarm can be added to be used as a shutdown alarm to avoid a reverse pressure on the inner mechanical seal in case the barrier system is not refilled in time or extreme barrier leakage occurs. The low-low alarm set point is set between the maximum seal chamber pressure and refill alarm point.

Alarm Strategies

In the fourth edition of API 682, two alarm strategies have been introduced. The alarm strategies, that are discussed in the standard, are divided in Fixed and Floating. Below is a short description of both strategies.

Fixed Alarm Strategy

As the description indicates, this strategy is making use of one fixed pressure alarm. This is the barrier pressure calculated at the minimum required barrier liquid volume in the accumulator and the maximum ambient temperature.

The graph in Figure 3 deviates slightly from the graph in the API 682 standard. The maximum barrier temperature curve is not shown because it is assumed that the barrier temperature does not affect the nitrogen temperature.

The gas pre-charge- and barrier refill pressure are depending on the ambient or gas temperature at the time of pre-charging or refilling barrier liquid from containers at ambient temperature. Since the temperature of the gas, inside of the bladder, is determining the barrier operating pressures, it is preferred to install a temperature indicator directly in the gas in the bladder. If the gas temperature is not measured, the ambient temperature close to the accumulator must be considered for pre-charge and barrier refill pressure.

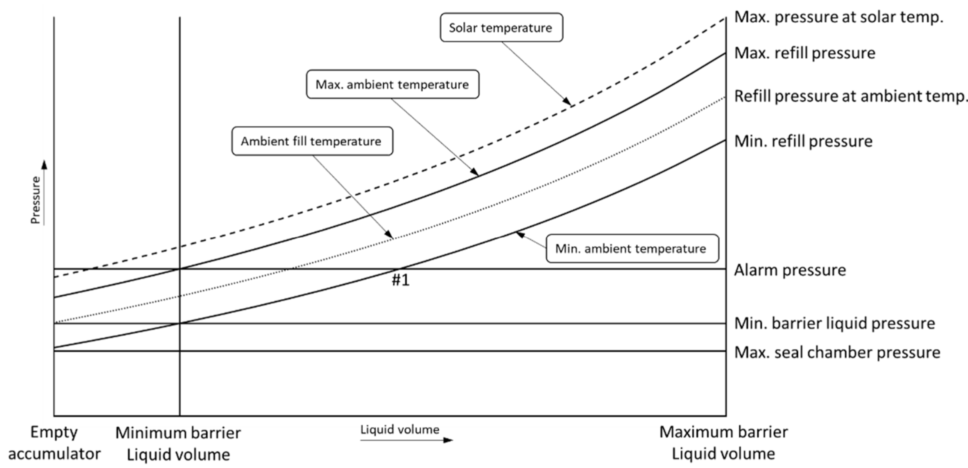


Figure 3: Fixed Alarm Strategy

The maximum barrier liquid volume in the accumulator is the volume at minimum ambient temperature and alarm pressure (point #1 in Figure 3) plus the total expected seal leakage volume in the required period between refills.

The solar temperature can be ignored if a sun-screen or shade is used to protect the accumulator against solar radiation.

The gas in the empty accumulator needs to be pre-charged to the pressure corresponding with the gas or ambient temperature at the time of pre-charging. Pre-charging of the accumulator can only be done without barrier liquid inside the accumulator. Before disconnecting the gas source from the bladder accumulator, it is good practice to give the gas the time to accommodate to the ambient temperature to achieve the correct pressure.

Before (re)filling the system with barrier liquid, operators need to measure the ambient temperature close to the bladder accumulator. This temperature must be used to determine the correct refill pressure which can be found on the name plate connected on the bladder accumulator.

Floating Alarm Strategy

With the floating alarm strategy, the alarm pressure is fluctuating with the ambient temperature (pressure alarm with a temperature bias). The alarm pressure must be continuously calculated for the actual gas temperature inside the bladder and compared with the barrier liquid pressure. To achieve this a pressure transmitter must be installed in the barrier liquid and a temperature transmitter in the gas inside the bladder. Both transmitters must be connected to the site distributed control system (DCS) or local controller for comparing the actual barrier liquid pressure against the calculated alarm pressure. This calculation may be performed by the DCS or local controller.

Pre-charging the gas in the empty accumulator is similar to that for a fixed alarm strategy. The pre-charge pressure is depending on the gas temperature inside the bladder. For a floating alarm strategy, the gas temperature must be measured with the temperature transmitter/indicator connected to the DCS or local controller.

The alarm pressure can be calculated as follows:

$$p_A = \frac{p_1 \cdot T_G}{T_1}$$

Wherein: p_A = Alarm pressure (absolute pressure)

p_1 = Barrier pressure (absolute pressure) at minimum temperature and minimum barrier liquid volume (data is provided by the mechanical seal and/or system manufacturer)

T_1 = Minimum ambient site temperature in Kelvin (K)

T_G = Temperature measured by the temperature transmitter in Kelvin (K)

It must be noted that the pressure p_1 is also the minimum pressure in the barrier fluid which means that p_A might not drop below p_1.

The volume can be neglected as the alarm pressure is calculated at a constant, guaranteed, minimum barrier liquid volume.

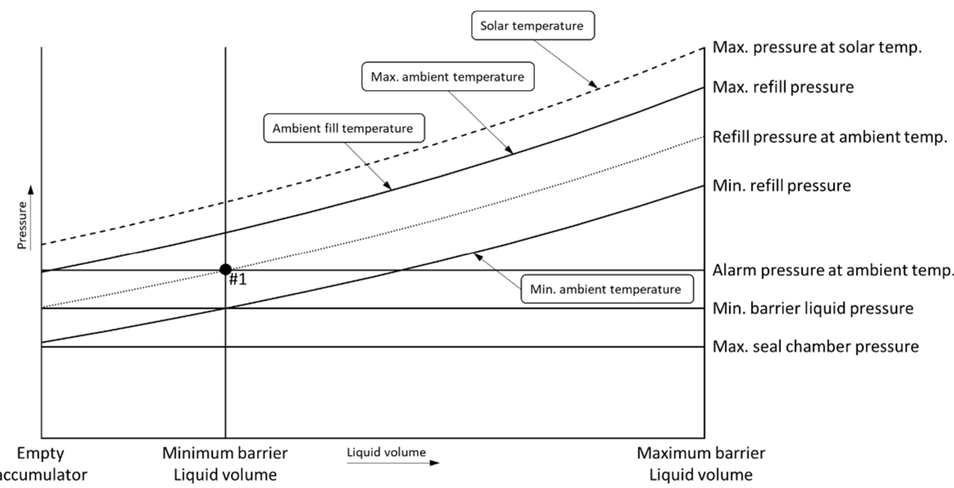


Figure 4: Floating Alarm Strategy

Advantage of the floating alarm strategy is that the total working volume required is less than that of the fixed alarm strategy. This might result in a smaller volume accumulator. At the same time the difference between maximum and minimum (alarm) pressure will be less for the floating alarm strategy compared to a fixed alarm strategy.

Summary of Pros and Cons for both strategies as discussed in API 682, 4th edition.

	API 682 4th Edition Plan 53B Alarm Strategies	
	FIXED	FLOATING
PROS	• Agreed minimum number of days between refills (28 days or greater unless otherwise agreed). • No early alarms due to temperature fluctuations • No excess of Design or MAWP in service	• Agreed minimum number of days between refills (28 days or greater unless otherwise agreed). • No early alarms due to temperature fluctuations • No excess of Design or MAWP in service • Smaller working volume/accumulator size
CONS	• Not user friendly due to fluctuating re-fill pressures (Nameplate) • Larger accumulator because of more working volume required • Ambient temperature measurement for every refill	• Not user friendly due to fluctuating re-fill pressures (Nameplate) • Complex algorithm for DCS • Problematic with changing conditions • Temperature transmitter for continuous gas temperature monitoring/calculation • Many potential failure modes (alarm/refill, DCS/Controller, temperature transmitter)

Alternative Alarm Strategy

One of the aspects, that is not addressed in the standard, is that operators need to refill to a pressure which is related to the ambient temperature at the time of refilling the system. This can lead to mistakes

- as operators do not have the ambient temperature at the location of the accumulator available.
- operators make mistakes in reading the nameplate.
- the nameplate becomes unreadable over time.

This can be prevented by a plan 53B system not discussed in so many words, in the API 682 standard. This proposed plan 53B system is making use of a Fixed Alarm strategy and Fixed Refill pressure.

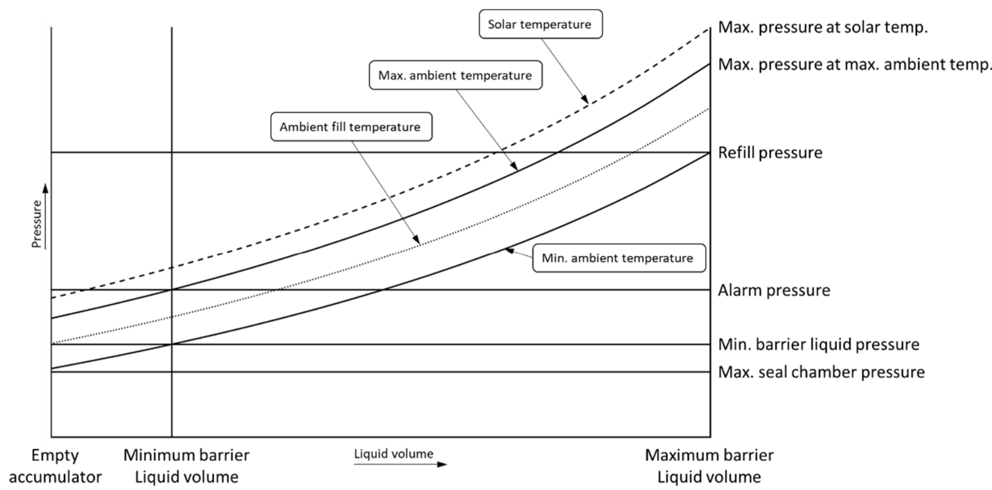


Figure 5: Fixed Alarm Strategy with Fixed Refill Pressure

With this strategy, two of the cons of a Fixed Alarm strategy (with floating refill pressure), can be eliminated. Operators always need to refill to the same barrier pressure without worrying about the ambient temperature and corresponding refill pressure. Only when pre-charging the bladder accumulator with gas is it critical to be done at a pressure corresponding with the ambient temperature.

The disadvantage is that the mechanical seal and plan 53B barrier system must be rated for a higher pressure than the refill pressure. As shown in Figure 5, refilling at a temperature below the maximum temperature, will result in an increase in pressure if, after refill, the ambient temperature increases. When refilling at the lowest temperature, the maximum barrier pressure can become relatively high, compared to the refill pressure, when the temperature increases to the maximum temperature. For this strategy the maximum allowable working pressure (MAWP) of the mechanical seal, plan 53B barrier system and pump must be considered as it can be exceeded by the maximum barrier pressure.

Another disadvantage of this method is that the maximum barrier liquid volume will be higher than that of the first two described alarm strategies, resulting in the need of a larger volume bladder accumulator.

Effect of Barrier Fluid Pressure on Mechanical Seals

Successful operation of mechanical seals is dependent on many different parameters. One of the parameters that directly affects mechanical seal performance, is the pressure applied or pressure differential across, the mechanical seal faces. Controlled mechanical seal face deformations are required to achieve low seal face leakage rates and low seal face wear rates. Mechanical seal face deformation can be divided into pressure- and thermal caused deformation. Pressure deformation is the mechanical deformation of the sealing seal faces caused by the pressure differential across the mechanical seal faces. Thermal deformation is thermal growth of the mechanical seal faces caused by the thermal differentials across the mechanical seal faces and seal face generated heat at the sealing interfaces. The pressure differential across the mechanical seal faces influences the hydraulic closing force on the seal faces, directly influencing the amount of seal face generated heat and thermal deformation.

In plan 53B systems the difference between maximum refill pressure and alarm pressure can be large. This can have impact on the seal performance such as fluctuating leakage rates and higher wear of the seal faces reducing the life cycle time of the mechanical seal.

The ambient temperature can have a large impact on the barrier pressure or more specifically, the differential between alarm and re-fill pressure. In API 682 4th edition, the below options are given to reduce the influence of the ambient temperature on the barrier pressure.

- use of a larger accumulator.
- use of an engineered auxiliary system design that has an MAWP above standard Category 1, 2 or 3 systems.
- use of an engineered seal rated for higher pressure than standard Type A, B or C seals.
- pressure relief valve in the barrier liquid piping.
- shade the accumulator to eliminate solar radiation effects. It is recommended to provide sunshades if it is known that the system will be located in direct sunlight.
- limit the impact of the ambient temperature range on the gas inside the accumulator by insulating and/or temperature control of the accumulator.

Other considerations to reduce the differential pressure between maximum refill and alarm, are:

- Don't use extreme temperatures for the calculations. Only historically average temperature data should be used.
- Allow a shorter refill frequency than the 28 days mentioned in API 682. This option requires customer/end user approval.

Specifically for high pressure applications

- Use of an automatic top-up unit (ATU). With this system the refill frequency becomes less important as it doesn't need frequent involvement from the operators. This allows the plan 53B system to run at a lower differential pressure between refill and alarm.
- Use of a plan 54 system.

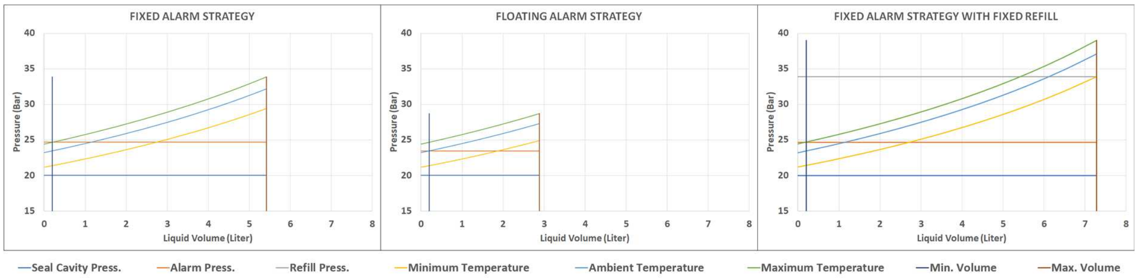
Conclusion

All methods described in this document do have pros and cons. A summary of the differences between the different strategies is shown in below table.

	Fixed Alarm Strategy	Floating Alarm Strategy	Fixed Alarm with Fixed Refill pressure
Implementation	Easy	Difficult	Easy
Operability/maintenance	Moderate	Moderate	Easy
Liquid volume in accumulator	Medium	Lowest	Highest
Differential between alarm- and maximum barrier pressure	Medium	Lowest	Highest
Pressure transmitter required	Yes	Yes	Yes
Temperature transmitter required	No	Yes	No
Use with automatic refill unit	Difficult	Difficult	Easy

Comparison of the results for the different strategies can be found below. The graphs are showing the results of the calculations for a system with the following data:

Maximum seal cavity pressure:	20 barg
Minimum temperature:	0°C
Maximum temperature:	40°C
Ambient temperature:	25°C
Accumulator size:	20 liter



Systems with fixed alarm and fixed refill pressure are the easiest to use. They don't need connection to the DCS other than only an alarm signal and operators need only take care of one refill pressure and do not need to consider the ambient temperature at the time of refilling. However, this system requires more volume than the other two and, although the refill pressure is equal to that of a fixed alarm strategy, the pressure can go up further which needs to be considered when selecting a mechanical seal and system.

Reducing the influence of temperature on the system with features described in this document, can reduce the difference between alarm and refill pressure.

The floating alarm strategy results in the smallest differential pressure between alarm and refill and requires the smallest volume. The system is however much more complex as it needs algorithms programmed into the DCS. Reliability of the DCS and pressure- and temperature transmitters is very important for proper and safe operation of the pump and mechanical seals. Failure of the system or one of the signals will increase the risk of a mechanical seal failure resulting in a pump shutdown and unsafe situation.

When requesting a dual pressurized mechanical seal with plan 53B system, End Users must clearly identify what method they want to use for, or how they want to operate, their application.

Historically, plan 53B systems have been delivered with Floating Alarm strategy, but no algorithm was implemented in the plant DCS. Additionally, systems with Floating Alarm strategy were quoted and ordered but changed during order fulfillment which needed redesign of, and modifications to the systems.