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Maximum Allowable Annular Surface Pressure (MAASP) Standards Calculations Study; a Field Case Study

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Abstract

Well integrity failures may arise during the production phase of a well in a field. Those failures could create a Sustained Casing Pressure (SCP), a pressure that is measurable at the wellhead that can not be bled-off. SCP must be addressed carefully to avoid any uncontrolled fluid flow to other formation or to surface. To maintain SCP value from degrading the other barrier integrity, the pressure threshold should be known and maintained for each annulus in a well. The maximum pressure threshold known as Maximum Allowable Annular Surface Pressure (MAASP). This case study will calculate MAASP from three wells in X field using three known methods as outlined in API RP90-2 and ISO 16530-1. API RP 90-2 defines two methods in calculation MAASP (known as MAASP – Maximum Allowavle Wellhead Operating Pressure), Simple Derating Method (SDM) and Explicit Derating Method (EDM). The result then compared and evaluted to know the differences, trend of MAASP for each method, and create a generalization of MAASP/depth for field rule of thumb. For A annulus, the MAASP obtained using API RP90-2 SDM and EDM method is always greater than that obtained using the ISO 16530-1 method. However, for B annulus, the MAASP obtained using the API RP 90-2 SDM method varies, occasionally being greater or less than the ISO 16530-1 method. While in C annulus, the MAASP obtained using the API RP 90-2 SDM and EDM methods is always less than the ISO 16530-1 method. The MAASP/depth generalization will be presented for MAASP ISO 16530-1.

INTRODUCTION

Well integrity has been considered one of the most critical concerns in the well design and construction phase. According to recent reviews of the industry incidents, statistics showed the major losses of the hydrocarbon, more than 80% were associated with asset integrity (Al Khamis et al., 2014). Elrefai et al. (2017) and Anders et al. (2008) had explained the benefits of having Well Integrity Management Systems, such as: reduced operational cost and fewer well barrier failure, improves process safety, early detection of well failure, preventive maintenance, increased production (by activation/restoring S/I wells), well registering (well-stock status) in detailed/updated status. Darmawan, 2021 stated that well integrity management has significantly improved the numbers of healthy wells, the risk of abandonment leakage at the end of well life cycle.

NORSOK D-010, Rev. 4, 2013 define well barrier as an envelope of one or several dependent well barrier elements preventing fluids or gases flowing unintentionally from the formation, into another formation or to surface and the well barriers shall be designed to ensure well integrity during the well's lifetime (called performance-based approach). Darmawan, 2021 created a gap analysis of Indonesia Well Abandonment with several international abandonment standards, where barrier philosophy should be established with performance-based approach to achieve proper permanent abandonment. Vignes, 2011 define barrier main

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Journal of Earth Energy Engineering
Vol. 12 No. 1, March 2023, pp 28-37

function to prevent, control, and reduce losses or mitigate undesired or accidental events. ISO 17776, 2016 define barriers as a measure which reduces the probability of triggering a hazard potential to cause damage or reduces the damage potential. The barriers can also be described as the safety margin based on i.e., material aging, etc, allowing the company to perform petroleum or other activities (Darmawan, 2021).

Some cases of well integrity failure were associated with well component failure, like the failure of surface casing, failure of production casing hanger, gas and oil leaks in tubular strings, production casing failure, and completion equipment failure (Torbergsen et al., 2012). This failure occurred because the components that functioned as well barriers were damaged due to corrosion, wear, and erosion. Therefore, the component could not resist the formation of fluid flow to enter the well containment during the production phase, which may create annular pressure known as SCP. SCP is an event of increased pressure in the annulus following bleed-off, which can occur due to fluid flowing in the annulus through the incompetence f well barrier element. The source of SCP can be any pressurized formation, including hydrocarbon-bearing formation, water-bearing formation, shallow gas zone, or shallow water zone.

SCP in the annuli shall be monitored regurarly to ensure its Build Up Rate (BUR) known and the pressures do not exceed the annular containment strength to ensure no uncontrolled release of hydrocarbons to surface. Darmawan, 2021 prepared the literature study of well integrity international standards, but not limited to:

1. ISO16530-1, Petroleum Natural Gas Well Integrity: Well Integrity for Operational Phase. March 2017.
2. NORSOK D-010, Well Integrity in Drilling & Well Operations. Rev.4, June 2013.
3. Norsk olije og gass guidelines 117, Well Integrity Guidelines, Rev. 6, November 2017.
4. API RP 65-2, Isolating Potential Flow Zones during Well Construction, 2nd edition, December 2010.
5. API RP 90-2, Annular Casing Pressure Management for Onshore Wells, 1st edition, April 2016.

AP RP 90-2, Annular Casing Pressure Management for Onshore Wells to know the calculations/safety needed for maintaining/monitoring SCP. The safety margin and threshold shall be established as outlined in the API RP 90-2 and ISO 16530-1. API RP 90-2 defines two methods in calculation MAASP (known as MAASP – Maximum Allowable Annulus Surface Pressure), Simple Derating Method (SDM) and Explicit Derating Method (EDM). Well construction data are required o calculate MAASP. Challenges comes in an old field where the well construction data sometime unavailable.

This paper will present calculations results and evaluation of MAASP from three wells in X field using three known methods as outlined in API RP 90-2 (SDM and EDM) and ISO 16530-1

METHOD

Figure 1 shows the process of this research by assessing and reviewing related standards, journals, papers, articles, and books, on MAASP calculations. The results of those various calculation methods were compiled, calculaed and analyzed. The calculation results presented as comparison to understand the trend, as well as creating a generalization approach for MAASP rule of thumb.

Torbergsen et al. (2012) stated that annuli pressures are to be monitored and maintained within the maximum allowable annular surface pressure known as MAASP. MAASP is the maximum pressure that annulus containment can withstand, without destroying the barrier integrity in the containment, or as explained by Torbergsen et al. (2012), MAASP is the absolute maximum pressure for a given annulus that is not to be exceeded at any time, as it represents the integrity limit for that annulus. For MAASP calculation, there are several safety factors that should be considered, such as, the pressure rating of all elements used in the well constructions, corrosion rate, wear, etc. MAASP is a life data, which may change due to equipment testing results, change of fluid produced or density change in annulus, wall thickness reduction, etc. The MAASP is estimated by determining the lowest rating of all the components (API RP 90-2, 2016; ISO 16530-1, 2017).

As mentioned in the introduction, there are methods in calculating MAASP, SDM and EDM (APR RP 90-2) and ISO 16530-1 method.

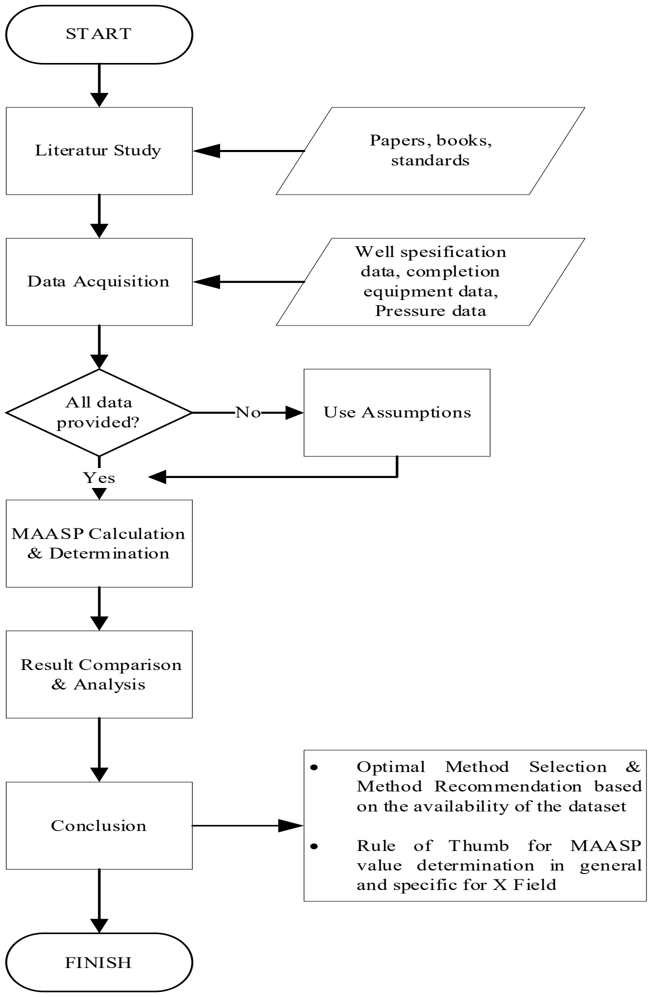


Figure 1. Flowchart of the research

I. API RP 90-2

The MAASP value is derived from the component with the lowest rating. Each component of the annulus's MAASP assessment should have a safety factor. For the MAASP calculation, the safety factor takes into account the following considerations (API RP 90-2, 2016), the minimum pressure rating of other elements within the casing string, such as couplings, threads, rupture disks, etc; unknown erosion or corrosion of the pipe; unknown casing wear; unknown age effects. The calculating component, which includes the following:

a. Wellhead rating component

Calculation :

$$WRC = 0.8\ x\ P_w$$

where

WRC : Wellhead Rating Component (psi)

Pw : Rated working pressure (psi)

b. Completions equipment rating

Calculation :

$$CRC = 0.8\ x\ (P_{cc} - \Delta P_{cc})$$

where

CRC : Completion equipment rating (psi)

Pcc : Rated working pressure from the completion unit (psi)

Journal of Earth Energy Engineering
Vol. 12 No. 1, March 2023, pp 28-37

ΔPcc : Differential pressure from the completion equipment (psi)

Safety factor : 0.8

c. Formation Fracture Breakdown Pressure (Only if there is an annulus that is directly connected to the formation.)

Calculation :

$$FFB = 0.8\, x\, [TVD.(FG - MWG)]$$

where

TVD : True Vertical Depth (ft)

FG : Minimum Formation Fracture Gradient (psi/ft or ppg)

MWG : Mud Weight Gradient (psi/ft or ppg)

Safety Factor : 0.8

d. Tubular De-rating

The tubular de-rating sections will be determined based on data availability. MAASP can be calculated in three ways based on tubular de-rating.

Default Designation Method (DDM)

It is the most conservative and straightforward method for determining MAASP on a tubular basis. This method does not require any additional data or analysis for tubular component derating.

MAASP determination:

- 100 psi for outermost annulus
- 200 psi for the other annulus in the well, without requiring further calculations.

Simple De-rating Method (SDM)

This method is appropriate for wells if the data for each phase have been adequately documented and tube corrosion and wear are not a significant source of concern. MAASP determination:

- 50% of the MIYP of the casing being evaluated or,
- 80% of the MIYP of the next outer casing or,
- 75% of the MCP of the inner tubular pipe body
- For the outermost pressure containing casing, MAASP can not exceed 30% of its MIYP

Explicit De-rating Method (EDM)

It is a suitable method when the casing string has sustained significant wear and when the tubular's erosion and corrosion values are known. MAASP determination:

- 80 % of the adjusted MIYP of the outer tubular string;
- 80 % of the adjusted MCP of the inner tubular string;
- 100 % of the adjusted MIYP of the next outer tubular string (provides an additional factor of safety);
- 100 % of the adjusted MCP of the outer tubular string, (i.e. the inner tubular of the next outer adjacent annulus)

Minimum internal yield pressure (MIYP) is the least internal pressure that causes the maximum stress in the pipe to achieve the minimum yield strength. Minimum collapse pressure (MCP) is the minimum external pressure that will lead the pipe to collapse without any internal pressure and axial loading

II. ISO 16530-1, 2017

The method is used for MAASP determination in the operational phase. This calculation method will be used to determine the key point in the annulus for MAASP determination. Additionally, this method is modified for each type of annulus, and the calculation is divided into two scenarios to serve as a guide for common well construction types. The MAASP should also be recalculated if the following conditions exist; any changes in well barrier elements acceptance criteria; any changes in the service type of the well; annulus fluid density change; tubing/casing wall thickness loss has occurred; changes in reservoir pressure outside the original load case calculation (ISO 16530-1, 2017). The type of case for every annulus that will be used for MAASP calculation can be seen in Figure 2 and 3. The calculation point tends to be the same with ISO 16350-2 (2014). The difference calculation point lies on packer element rating, liner hanger element rating, and line lap burst points.

Table 1. MAASP Calculation for A-Annulus (Source: ISO 16530-1, 2017)

Point	Item	Case	MAASP Equation
1	Safety valve collapse	Both	$P_{MAASP} = P_{PC,SV} - [\, D_{TVD,SV}.\left(\nabla P_{MG,A} - \nabla P_{MG,TBG}\right)]$
2	Accessory collapse	Both	$P_{MAASP} = P_{PC,ACC} - [\, D_{TVD,ACC}.(\nabla P_{MG,A} - \nabla P_{MG,TBG})$
3	Packer Collapse	Both	$P_{MAASP} = P_{PC,PP} - [\, D_{TVD,PP}.(\nabla P_{MG,A} - \nabla P_{MG,TBG})$
3	Packer element rating	Both	$P_{MAASP} = P_{PKR} + P_{FORM} - \left(D_{TVD,PP}\,.\nabla P_{MG,A}\right) - \left[\nabla P_{FORM}\,.\left(D_{TVD,FORM} - D_{TVD,PP}\right)\right]$
3	Liner element rating	2	$P_{MAASP} = P_{LH} + \left[D_{TVD,LH}.\left(\nabla P_{FP,FORM} - \nabla P_{MG,A}\right)\right] - \left[\nabla P_{FORM}\,.\left(D_{TVD,FORM} - D_{TVD,LH}\right)\right]$
4	Liner hanger packer burst	2	$P_{MAASP} = P_{PB,LH} - [\, D_{TVD,LH}.(\nabla P_{MG,A} - \nabla P_{BF,B})$
5	Tubing collapse	Both	$P_{MAASP} = P_{PC,TBG} - [\, D_{TVD,PP}.(\nabla P_{MG,A} - \nabla P_{MG,TBG})$
6	Formation strength	2	$P_{MAASP} = D_{PC,shoe} - [\, D_{TVD,PP}.\left(\nabla P_{MG,A} - \nabla P_{MG,TBG}\right)]$
7A	Outer casing burst	1	$P_{MAASP} = P_{PB,B} - [\, D_{TVD,PP}.(\nabla P_{MG,A} - \nabla P_{BF,B})$
		2	$P_{MAASP} = P_{PB,B} - [\, D_{TVD,LH}.\left(\nabla P_{MG,A} - \nabla P_{BF,B}\right)]$
7B	Liner lap burst	2	$P_{MAASP} = P_{PB,B} - [\, D_{TVD,PP}.(\nabla P_{MG,A} - \nabla P_{BF,B})$
8	Wellhead rating	Both	Equal to to wellhead working pressure rating
	Annulus test pressure		Equal to the annulus test pressure

Table 1 show the equations used to calculate MAASP of the A-Annulus, where the most data used mostly the tubular and its accessories, the wellhead ratings, pressure test, and the formation pressure/strength. Table 2 shows the equation to calculate MAASP of the B and C-Annulus, where the data used mostly the outer and inner casing strength, wellhead rating and pressure test. The symbols and abbreviations used in Table 1 and Table 2 are explained in detail in Table 3 below.

Table 2. MAASP Calculation for B and C -Annulus (Source: ISO 16530-1, 2017)

Point	Item	Case	MAASP Equation

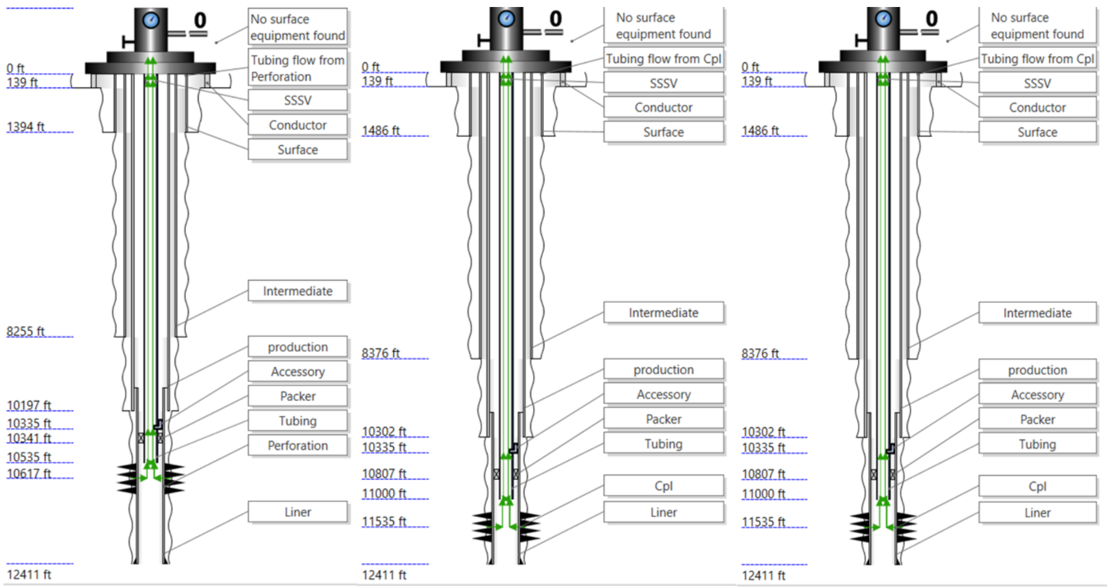
Journal of Earth Energy Engineering
Vol. 12 No. 1, March 2023, pp 28-37

1	Formation Strength	Both	$P_{MAASP} = D_{TVD,shoe,B}.(\nabla S_{FS,B} - \nabla P_{MG,B})$
2	Inner casing collapse	Both	$P_{MAASP} = P_{PC,A} - [D_{TVD,TOC}.(\nabla P_{MG,B} - \nabla P_{MG,A})]$
3	Outer casing burst	Both	$P_{MAASP} = P_{PB,B} - [D_{TVD,SH}.(\nabla P_{MG,B} - \nabla P_{MG,A})]$
4	Wellhead rating	Both	Equal to wellhead working pressure rating
	Annulus test pressure	Both	Equal to the annulus test pressure

Table 3. Symbols and abbreviations used in MAASP calculations

Parameter		Description
Symbol	**Abbreviation**	
DTVD	TVD	True vertical depth (TVD), expressed in meter (Depth is relative to the wellhead and not the rotary kelly bushing)
∇pBF	BF	Base fluid pressure gradient in annulus, expressed in kilopascals per
pFORM	FORM	Formation pressure
∇pFORM	FORM	Formation pressure gradient, expressed in kilopascals per metre
pMAASP	MAASP	Maximum allowable annulus surface pressure, expressed in kilopascals
∇pMG	MG	Mud or brine pressure gradient, expressed in kilopascals per metre
pPC	PC	Casing collapse pressure resistance, expressed in kilopascals. (Safety factor should be applied to PC prior to calculating the MAASP value)
pPB	PB	Casing burst pressure resistance, expressed in kilopascals. (Safety factor should be applied to PB prior to calculating the MAASP value)
pPKR	PKR	Production packer operating pressure rating, expressed in kilopascals
∇SFS	FS	Formation strength gradient, expressed in kilopascals per meter
A, B, C, D		Designation of the annulus
ACC		Accessory (e.g., SPM or landing nipple)
BF		Base fluid (refers to base fluid of mud in outer casing)
FORM		Formation
LH		Liner hanger
PP		Production packer
RD		Rupture disk
SH		Casing shoe
SV		Safety valve
TBG		Tubing
TOC		Top of cement

Well Schematic



(a) (b) (c)

Figure 4. Well schematics, (a) D-3, Case-1, (b) N-1, Case-2, and (c) N-3, Case-2.

Table 4. TOCs of D-3, N-1 and N-3 Wells

Well TOC	Depth (ft)
Well D-3	
B annulus	8251
C annulus	492
Well N-1	
B annulus	7365
C annulus	902
Well N-3	
B annulus	7546
C annulus	722

RESULT AND DISCUSSION

Case Study

These three wells are identical in design (please refere to Figure 4), oil wells with natural flowing, and have been operating for more than 12 years. D-3, N-1, N-3, are the well designations. The type of every wells is vertical well. Each well has three datasets: well specification information, completion equipment information (including burst and collapse utilization factors), and pressure information (including wellhead rating, annulus test pressure, top of cements-TOCs as outlined in Table 4, and formation pressure data). The design is typical with well structure consist of three casings, one tubing, and one liner. In addition, this well is equipped with a packer, Subsurface Safety Valve (SSSV), and accessory as completion equipment. D-3 will use case-1 and the rest will use case-2.

According to the most recent corrosion log survey, corrosion is occurring at a rate of up to 17% in production tubing. This corrosion value will be converted to a burst and collapse utilization factor to calculate the API RP 90-2 EDM method for tubular derating sections. Due to a lack of evidence about the presence of corrosion in the casing, the value of corrosion experienced in casing was presumed to be identical to the value experienced in production tubing. Another assumption made in this study is that each annulus is not directly connected to the formation, i.e. cemented, until at least above the shoe of the

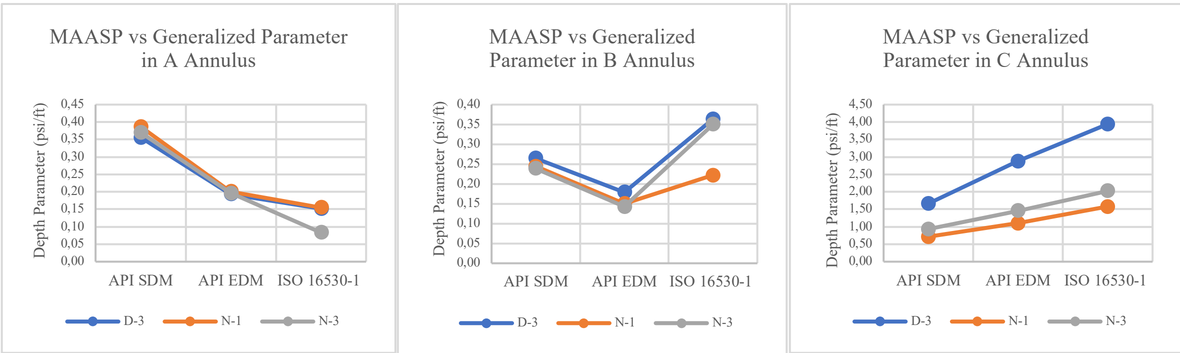
Journal of Earth Energy Engineering
Vol. 12 No. 1, March 2023, pp 28-37

annulus's outer casing. As a result, the MAASP determination will exclude the formation strength section calculation.

Calculation Comparison

Table 5. MAASP Calculation Result from Three Wells

Annulus/MAASP (psi)	Well D-3			Well N-1			Well N-3		
	API SDM	API EDM	ISO 16530-1	API SDM	API EDM	ISO 16530-1	API SDM	API EDM	ISO 16530-1
A Annulus	3421	1862	1459	4000	2079	1600	4000	2116	900
B Annulus	2184	1475	3000	1800	1106	1635	1800	1079	2642
C Annulus	819	1415	1940	675	1038	1489	675	1055	1462



(a) (b) (c)

Figure 5. MAASP vs Generalization Parameter Comparison for, (a) A annulus, (b) B annulus, and (c) C annulus

Discussions

As assets mature and older, well integrity problems increase, risk management becomes more intense and increased vigilance and better surveillance is required to ensure wells and assets are healthy and have trouble-free operation (Kumar et al., 2014). After all of the considerations and calculations made, the ISO 16530-1 method is the most optimal method for obtaining the MAASP value in a well since this method is suitable with the comprehensive data, provide more MAASP calculation component constraints and gives fairly clear calculation guidelines. This ISO 16530-1 method focused on each barrier elements for the envelope, to work to prevent, control and mitigate undesired events. API RP 90-2 simple derating method (SDM) is recommended for applications where field and well data are scarce, whereas API RP 90-2 explicit derating method (EDM) is recommended if there is data on tubing and casing corrosion.

For A annulus, the value demonstrates a downward trend when the employment of methods with limited data availability results in a higher value than the calculation method that utilizes all available data. The API RP 90-2 SDM method which utilizing limited dataset, resulting value 2.34-4.44 times larger than the ISO 16530-1 method as the optimal method, whilst API RP 90-2 EDM estimates value 1.28-2.35 times larger than the ISO 16530-1 method's value. Please refer to Figure 5(a).

For the B annulus, the comparison value exhibits an inconsistent trend for the API RP 90-2 SDM method and shows an uptrend for API RP 90-2 EDM method. The use of the API RP 90-2 EDM method will give smaller results than the ISO 16530-1 method, with a value of 0.41-0.68 times smaller, whereas The API RP 90-2 SDM method producing a value 0.68-1.10 times that of the ISO 16530-1 method. Please refer to Figure 5(b).

Outermost for C annulus, comparison value shows an upward trend, when the implementation of methods with limited data availability results in a lower value than the calculation method that use all available data. The API RP 90-2 SDM method value being 0.42-0.46 times smaller than the ISO 16530-1 method value and the API RP 90-2 method result being 0.7-0.73 times smaller than the ISO 16530-1 method result. Please refer to Figure 5(c).

Result of the ratio between MAASP value and depth of annulus for necessity of rule of thumb MAASP determination in another wells in X field are :

- For A annulus, the value averaged ratio with using the API RP 90-2 SDM method is 0.37 psi/ft, while API RP 90-2 EDM method gives value 0.2 psi/ft and the ISO 16530-1 is 0.13 psi/ft. Depth reference is the packer depth.
- For B annulus, averaged ratio using the API RP 90-2 SDM method produces value of 0.25 psi/ft, the API RP 90-2 EDM gives value 0.16 psi/ft and the ISO 16530-1 gives 0.31 psi/ft with depth reference TOC of B annulus.
- For C annulus, the API RP 90-2 SDM average ratio value is 1.11 psi/ft, the API RP 90-2 EDM gives average ratio value around 1.81 psi/ft, and the ISO 16530-1 produces result about 2.52 psi/ft with depth reference TOC of C annulus.

CONCLUSION

Based on this literature research, there are some summaries that could be derived:

- After all of the considerations and calculations made, the ISO 16530-1 method is the most optimal method for obtaining the MAASP value in a well since this method is suitable with the comprehensive data, provide more MAASP calculation component constraints and gives fairly clear calculation guidelines.
- MAASP rule of thumb with ISO 16530-1 for the field could be simplify for A-Annulus 0.18 psi/ft, B-Annulus 0.81 psi/ft, and C-Annulus 2.52 psi/ft with respect of the depth references in annuli.

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