A PROPOSED CORRELATION FOR PREDICTING THE PERFORMANCE OF CRITICAL FLOW THROUGH SURFACE WELLHEAD CHOKES.

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ABSTRACT

Accurate prediction of the behavior of multi-phase flow through wellhead chokes is required for modern production design and optimization of oil well performance.

This study presents the development of an empirical correlation that predicts the performance of simultaneous flow of oil, gas and water mixture through wellhead chokes. The correlation was derived on the basis of actual production data. The newly developed correlation predicts liquid flow rates as a function of flowing wellhead pressure, gas/liquid ratio and surface wellhead choke size.

The study involves a comparison between the available choke correlations based on 200 field tests from twenty wells. The correlations used in this study are those of Gilbert, Al-Attar, Ros, Baxendall, Achonge, and Secen. The Absolute average percent difference is computed for each correlation. Secen correlation has the lowest error compared to the other examined correlations. However, none of the tested correlations is found to be accurate in all ranges of wellhead pressure, gas/ liquid ratio and choke size. The validity of each of these correlations is limited to a specific operational condition for which the correlations are determined. As a result the strength of those correlations for predicting the actual flow rate is restricted.

Due to discrepancy of results obtained by the included correlations, multiple regression analysis using the statistical technique using the Doolittle method is used to create correlation that best fit the measured data. The proposed correlation is similar to the Gilbert-type empirical correlation.

The new correlation was examined against other correlations using another 110 well test data. The results are found to be statistically very good compared to those predicted by other published correlations considered in this work.

INTRODUCTION

There are two surface conditions under which a flowing well produces, it may produce with a choke at the surface or it may produce with no choke at the surface. The majority of all flowing wells utilize surface choke to isolate the underground reservoir from pressure variations in the surface equipment, and also they are used for preventing or reducing the water production. Wellhead chokes usually are selected so that fluctuations in the line pressure downstream of the choke have no effect on the well flow rate.

The phenomenon of multiphase flow (liquid and gas) happens in the wellhead of the majority of the producing wells. Flow through the wellhead chokes is mainly divided into two critical and subcritical conditions. The critical flow condition refers to the state at which the flow rate researches a maximum amount independent of the downstream and upstream pressure difference of the choke. For this condition to exist, downstream line pressure must be approximately 0.55 or less of the tubing head or upstream pressure.

Various development correlation have been published that present theories and correlations for describing simultaneous liquid and gas flow through wellhead chokes. Although numerous multiphase correlations are included in the literature, almost all of them are limited to a special operational condition in which the correlations are driven. As a result, the strength of those correlations for predicting the actual flow rate is restricted.
Inaccurate flow rate predictions could lead to gas /water coning, sand entry, and excessive pressure at the separator which can be a major factor of killing the producer well.

The purpose of this study is to develop an equation that can predict the performance of multiphase flow through wellhead chokes based on a total of 200 field tests.

In this paper, an empirical correlation of the form originally proposed by Gilbert has been developed for the critical flow regime. This type of correlation is simple to use in the field and does not require any information about the PVT properties of the produced fluids. Statistical error analysis was used to compare the new empirical correlation developed in this study with similar correlations existing in the literature. The results showed that the new correlation delivered the best accuracy.

CORRELATION OF MULTIPHASE FLOW THROUGH WELLHEAD CHOKE

Gilbert (1945) developed the most popular multiphase flow surface choke correlation assuming a knife-edge choke and making several simplifying with regard to the pressure/volume characteristic of the oil and gas. He proposed a correlation relating surface production with the wellhead-choke size, wellhead pressure, and gas oil ration (GOR), as follows:

$$Q = A\frac{P_{wh}S^B}{GOR^C} \quad \text{……………………………………………………………………………….(1)}$$

$A = 0.1, B = 1.89, C = 0.546$

Where Q is the gross liquid rate (bbl/d); GOR is producing at standard conditions (Mscf/bbl); Pwh is wellhead pressure (psig); and S is bean size(1/64 in.).

Gilbert formula assumes that actual mixture velocity through the bean exceeds the speed of sound, therefore, the downstream pressure or flow line pressure has no effect on the rate of upstream pressure. The speed of sound is known to occur when the upstream pressure is at least twice the downstream pressure. Gilbert stated, however, that his formula was good when the downstream pressure was less than 0.7 of the upstream pressure. Other Gilbert-type multiphase flow choke correlations by other researchers were proposed for the critical condition. Theses correlations have the same form as that of Gilbert (1954) but with differing constant and variables exponents.

Based on the statistical analysis of production data from 155 well tests, 20 of which are from the East Baghdad Oil Field, Al-Attar and Abdul Majeed (1988) compared the correlations of Gilbert, Ashford, Poetmann and Beck in an attempt to select the best correlation that could best fit the field tests. The best correlation was then revised for East Baghdad Oil Wells. The correlation has the form of Gilbert equation with different constants, as follows:

$$Al - Attar: \quad Q_f = a.Pth^b.S^c.MGLR^d \quad \text{………………………………………………….(2)}$$

They concluded that none of the correlations they tested was found to be most accurate in all ranges of flow variables. From an overall comparison of the correlations they tested, these investigators reported that the least error is obtained with the Gilbert correlation. This correlation was then revised to get the best fit of the observed data.
Ros (1960) developed a correlation very similar Gilbert's (1954) correlation, but with different constant and exponent, as follows:

$$Q = A\frac{P_{wh}S^B}{GOR^C} \quad \text{…………………………………………………………………...……..(3)}$$

$A = 0.574, B = 2, C = 0.5$

In addition to the above correlations, several investigators used field data to develop correlations to predict flow rates in the critical region. These relationships are given below:

$$Baxendell: \quad Q_f = \frac{P_{th\,.}S^c}{a.GLR^b} \quad \text{……………..…………………………..…….. (4)}$$

$$Achong: \quad Q_f = \frac{P_{th\,.}S^c}{a.GLR^b} \quad \text{..……………………………..……………….(5)}$$

$$Secen: \quad Q_f = a.\frac{P_{th\,.}S^c}{GLR^b} \quad \text{……………………………….….……..(6)}$$

Where *A*, *B*, and C are constants given in table 1 for various investigators.

EXAMINE THE SELECTED CORRELATIONS

Data of 200 production tests were collected from 20 wells, including the liquid-flow rate QL, gas liquid ratio GLR, choke size S, and tubinghead pressure Pth. The different correlations investigated in this study were tested for the whole data range.

It is important to know the type of fluid flow through wellhead chokes, i.e. whether it is critical or subcritical to use the appropriate correlation for critical flow condition. For this reason the ratio of the downstream pressure to the upstream pressure for each test is determined. It is found that all wells tests are in critical flow. Accordingly, some of the available correlations of critical multiphase flow through wellhead chokes in the literature are selected for the purpose of our study; namely Gilbert, Al-Attar and Abdulmajed, Ros, Baxendall, Achonge, and Secen.

The observed flow rate versus predicted flow rate was plotted in figure1.Figure 1 illustrates that Achong and Secen correlations are over predict production rate, while Gilbert, Al-Altar and Abdulmajed, Ros and Baxendell correlations are under-predict production rate. The accuracy of the correlation was determined by comparing the calculated and measured values of flow rate. The closer the plotted data points to the 45° straight line drew on the cross plot of these values, the more accurate is the correlation. The figure shows that all predicted data is scattered and no correlation match the observed data. Therefore, these equations are then examined using four statistical measures of reliability. These are the percent difference, average of percent differences, absolute average differences, and standard deviation.

The definition of these statistical measures is:

percent differences $D = \left(\frac{Q_{OB} - Q_P}{Q_{OB}}\right) X\ 100$ ………………………..(7)

$Q_{OB} = \text{Observed}$, $Q_P = \text{Predicted}$

Average of percent differences $D_a = \frac{\sum_{i=1}^{n} D_i}{n}$ ………………………(8)

$D_i = \text{percent differences}$, $n = \text{number of tests}$

Absolute average of percent differences $AD_a = \frac{\left|\sum_{i=1}^{n} D_i\right|}{n}$ ………...(9)

Standard deviation $SD = \sqrt{\frac{\sum_{i=1}^{n} (D_i - D_a)^2}{n-1}}$ ………………………(10)

The statistical results of these calculations are shown in table 2. The accuracy of the correlation was determined by comparing the calculated and measured values of flow rate.

Average of percent differences (Da) is not good indicator to compare the results because it terminates the positive and negative error for under-predict and over-predict rates. Thus, absolute average of percent differences (Ada) was used to compare the correlations results. Although Secen correlation was the best overall to predict the flow rate, we need to examine this correlation against the other correlations in ranges of each flow variable. Therefore, tubing head pressure (Thp), gas-liquid ratio (GLR) and choke size (S) were divided into groups and flow rate for each group was calculated using the selected correlations. Table3 illustrates different groups for each variable. Predicted flow rate was calculated using the same correlations for each range of Pth, GLR and S. Then statistical measures were used to compare these correlations. The results were plotted in figures 2, 3, 4 which show that none of correlations work best for all ranges of the flow variables.

FORMULATION OF THE PROPOSED CHOKE PERFORMANCE EQUATION

Due to discrepancy of results obtained by the correlations discussed earlier, multiple regression analysis using the Doolittle method statistical technique to create a correlation that best fit the measured data. The proposed correlation is similar to the Gilbert-type empirical correlation.
The general form of Gilbert and revised correlations is:

$$Q_f = a.Pth^b.GLR^c.S^d$$

Taken the logarithm of the above equation
$LogQ_f = Loga + b.LogP_{th} + c.LogGLR + d.LogS$, and it is a linear equation. Hence, a curve fitting technique can be applied using available production data to determine the constants (a, b, c, d).

The revised correlation is found to take the following form:

$$Q_f = 0.344 Pth^{0.592} . MGLR^{-0.211} . S^{1.245} \quad \text{……………………….(11)}$$

VALIDITY AND RESULTS OF THE DEVELOPED CORRELATION

Validity of the critical flow correlation developed in the present work was examined and compared to that of other selected correlations using 110 measured data points. In overall, the results in table 4 show in term of ADa statistical measure that the highest accuracy was obtained with the new correlation.

Because the flow variables (Pth, GLR, & S) have a major effect on the flow rate found in multiphase flow, an analysis of the prediction of errors on the basis of the ranges of these variables should point out some of the strengths and weaknesses of the individual correlations. Table 5 shows the various ranges of these variable from 110 tests and the statistical analysis (Ada) using the existing correlation beside the developed one. In addition to the overall statistical results in table 5 further information about the performance of the multiphase flow through choke correlations are shown in figure 5 through 7. The table and the figures illustrate the effects of wellhead pressure, produced gas/liquid ratio and choke size on the performance of each prediction method.

Table 5 displays that the developed correlation has fewer errors in most ranges of flow variables and it can be concluded that the revised correlation could best fit the production rates.

Figures 5 and 6 demonstrate that the developed correlation is the best one for all ranges of tubing head pressure and gas/liquid ratio compared to the other correlations. In-addition, figure 7 indicates that the developed correlation is the best one for the choke size below (28/64-in) and does quit well above that range.

CONCLUSION AND RECOMMENDATION

- The critical multiphase flow through wellhead restrictions is investigated and a new correlation is proposed. The correlation is developed by using 200 field tests representing critical flow condition and
- None of the tested correlations available in the liturature is found to accurate fit all ranges of the flow variables.
- Statistical analysis show that the new correlation is better than exisiting corelations for both the data used to develop the new correlation and the data used to validate it.
- It is recommended that more data be collected using well tests to further valiate the developed correlation.

REFRENCES

Gilbert, W.E. 1954. Flowing and gas-lift well Performance. API Drilling & Production Practice 20(195):126-157.

Baxendell, P.B. 1957. Bean performance-lake wells. Internal report, October 1957.

Ros, N.C.J. 1960. An analysis of critical simultaneous gas-liquid flow through a restriction and its application to flow metering. Applied Science Research 9 (February): A-374.

Achong, I .1961. Revised Bean Performance Formula for Lake Maracaibo Wells, Internal report, Shell Oil Co., Houston

Secen, J.A. 1967. Surface-choke measurement equation improved by field testing analysis; Oil and Gas Journal, pp. 65-68, August 1967.

Al-Attar, H.H., and Abdul-Majeed, G.H.1988. Revised bean performance equation for East Baghdad Oil Wells; SPEPE, February 1988.

Table 1- Correlations constants

Correlation	a	b	c	d
Gilbert	10	0.546	1.89	1
Al-Altar and Abdulmajed	0.016	0.831	1.63	0.471
Ros	17	0.5	2	1
Baxendell	9.56	0.546	1.93	1
Achong	0.262	0.65	1	1
Secen	0.067	2	0.5	1

Table 2- statistical results from 200 tests for each tested correlation

	Da	ADa	SD
Gilbert	20.6	26.1	21.85
Al-Atal & Abdulmajed	16.8	23.8	21.55
Ros	11.9	22.0	24.26
Baxendell	5.8	20.3	25.88
Achong	2.3	20.4	26.0
Secen	-1.0	19.3	27.8

Table 3- flow variables (Pth, GLR, S) ranges from 200 tests and number of tests for each range.

Pth[psi]		GLR[SCF/STB]		Choke Size (S)[1/64"]	
Range	# of tests	Range	# of tests	Range	# of tests
120 – 299	20	<500	58	20	43
300 – 399	48	500 – 600	77	22	31
400 – 499	37	601 – 700	43	24	79
500 – 599	78	701 - 1000	22	26	29
600 - 1000	17			28 - 64	18
Total # of tests	200		200		200

Table 4 compare examined correlations with new correlation using 110 tests(validation)

	Gilbert	Al-Atar & Abdulmajed	Ros	Baxendell	Achong	Secen	New correlation
ADa	28	27	27	26	23	27	19

Table 5 flow variables (Pth, GLR, S) ranges for 110 tests, number of tests for each range and ADa measure results

		ADa						
Pth		Gilbert	Al-Atar	Ros	Baxendell	Achong	Secen	New
Range	# of tests							
440 - 499	22	32	29	31	28	21	27	17
500 - 599	72	31	29	28	26	25	26	22
600 - 1000	16	13	11	18	22	18	33	11
GLR								

Range	# of tests							
450 – 599	41	29	27	31	31	25	35	25
600 – 699	48	28	26	25	23	21	22	17
700 - 1000	21	28	27	23	22	23	22	15
S								
Range	# of tests							
20	17	29	26	25	23	21	22	18
22 – 24	40	31	28	25	23	24	19	14
26 – 28	31	26	26	22	21	24	22	22
30 - 36	22	28	26	38	41	23	54	26

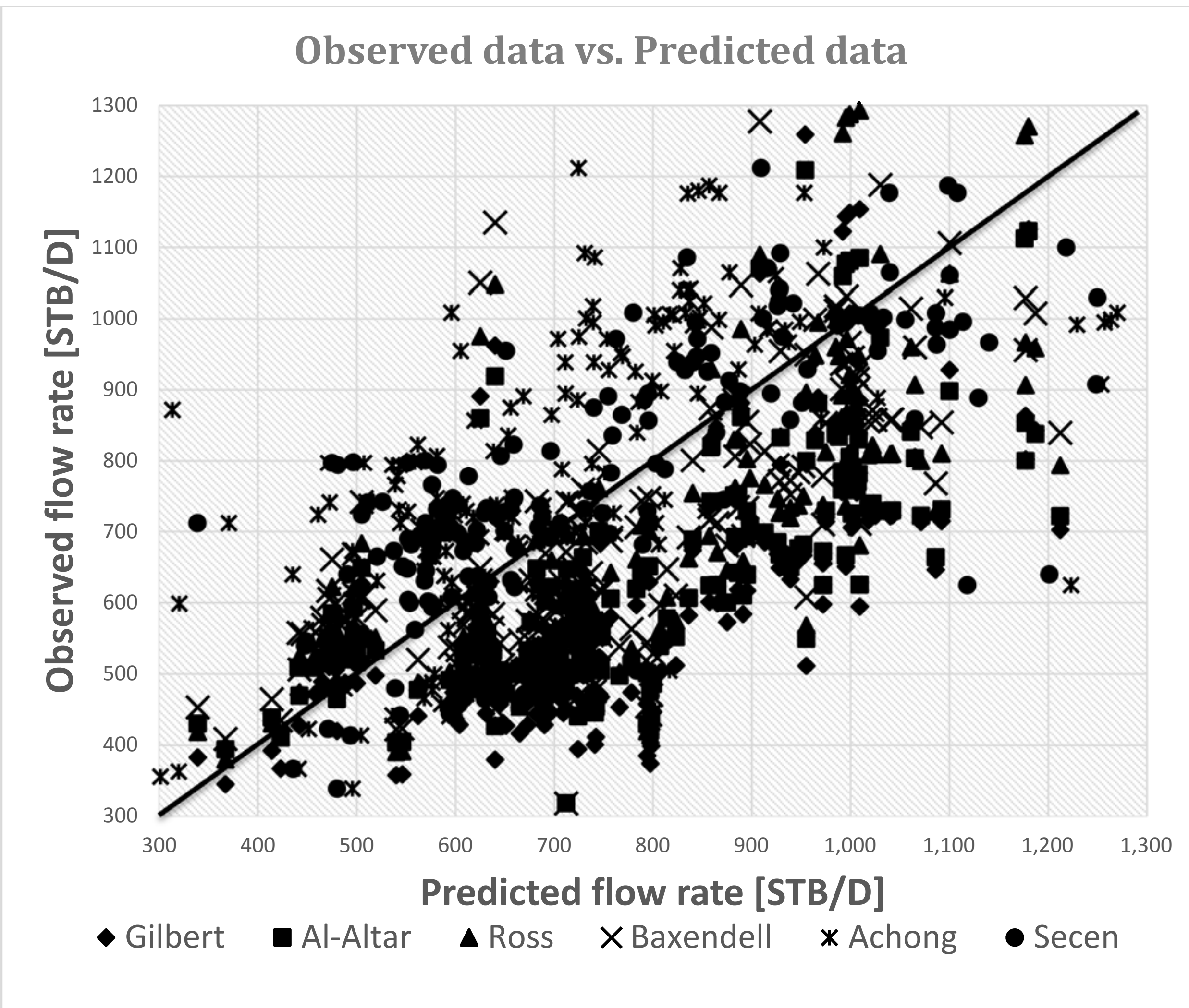

Figure 1- Observed vs Predicted 200 tests

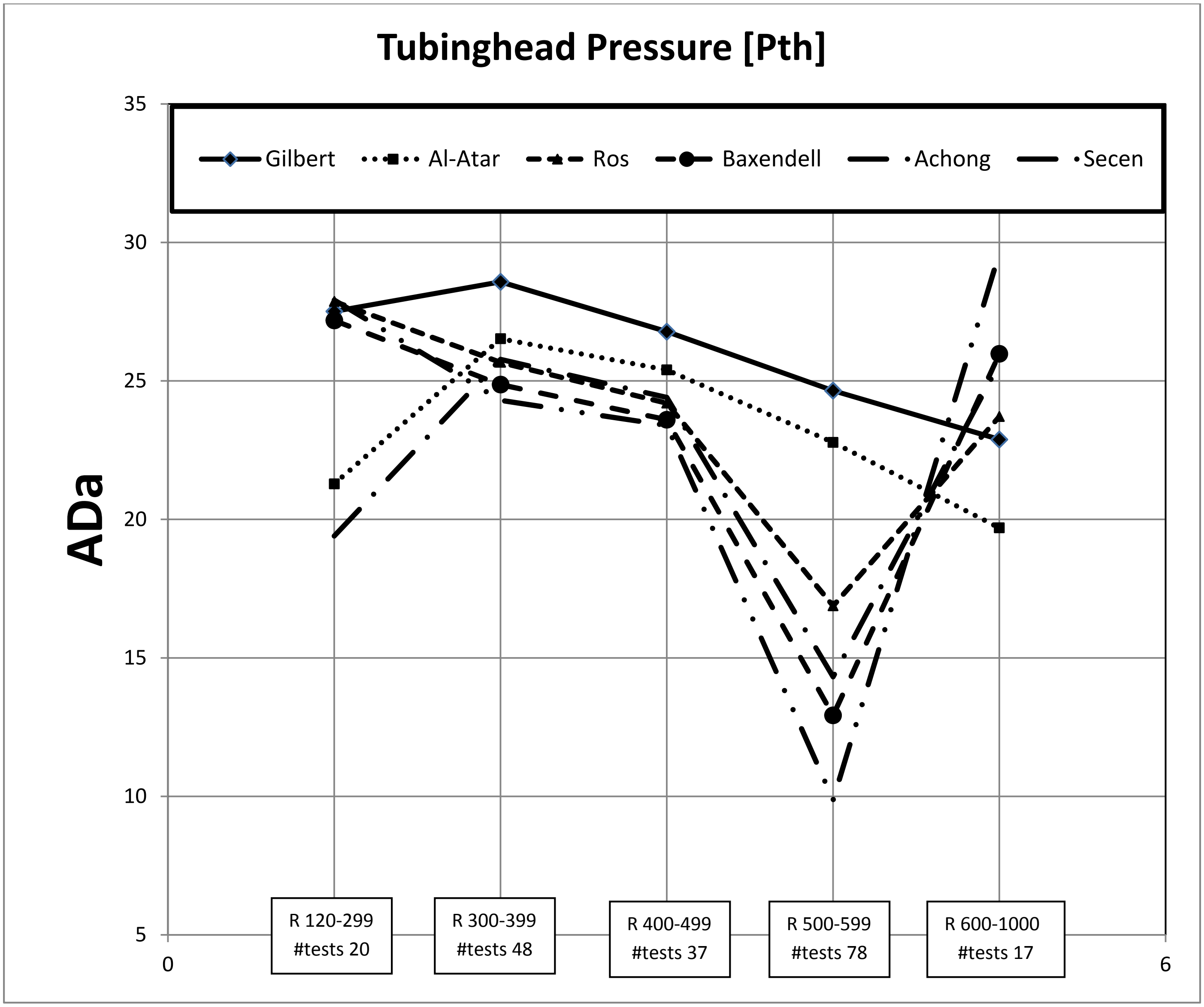

Figure 2- Tubinghead (Pth) ranges to compare tested correlations(R=range)

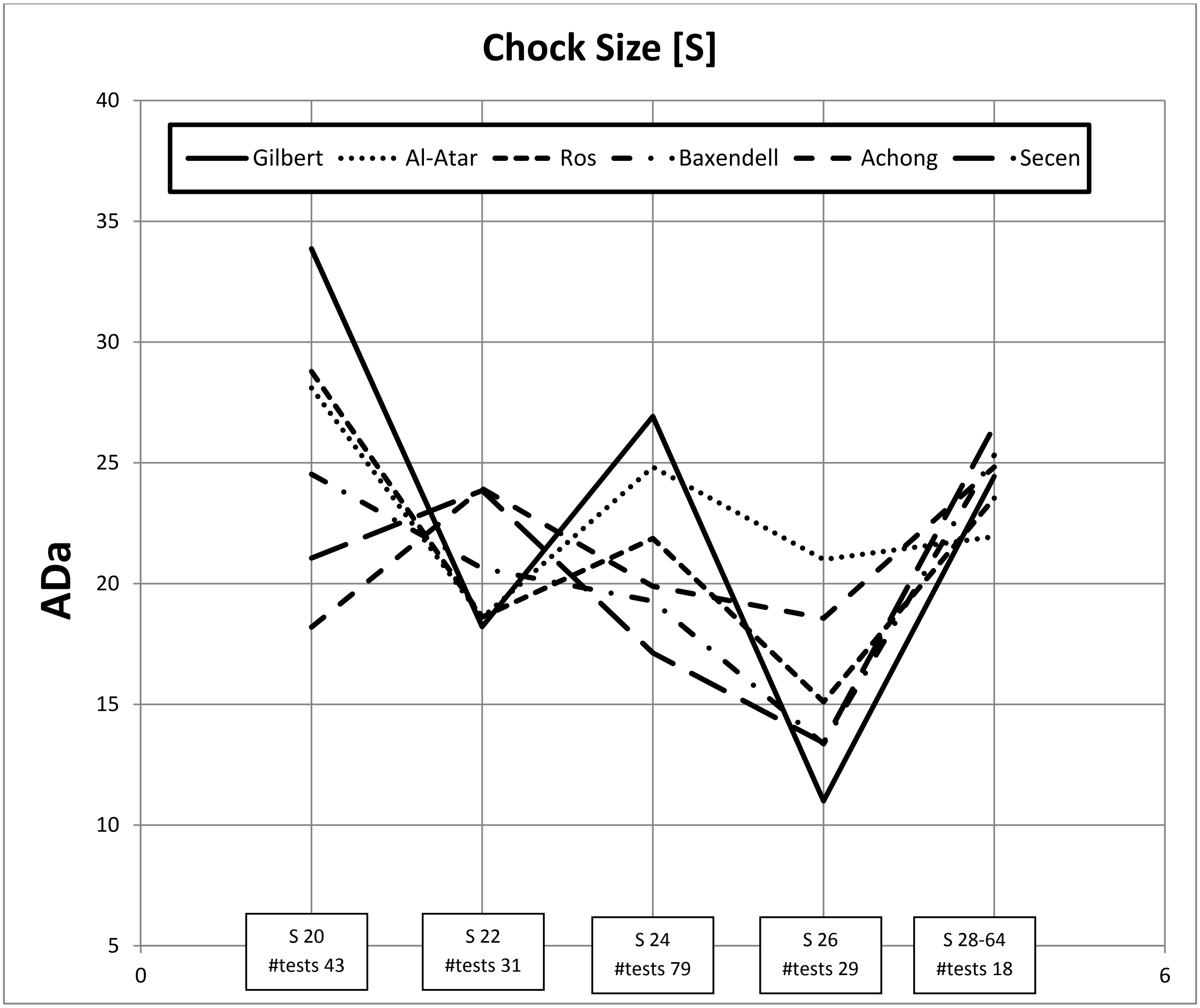

Figure 3- Choke size (S) ranges to compare tested correlations(S choke size 1/64”)

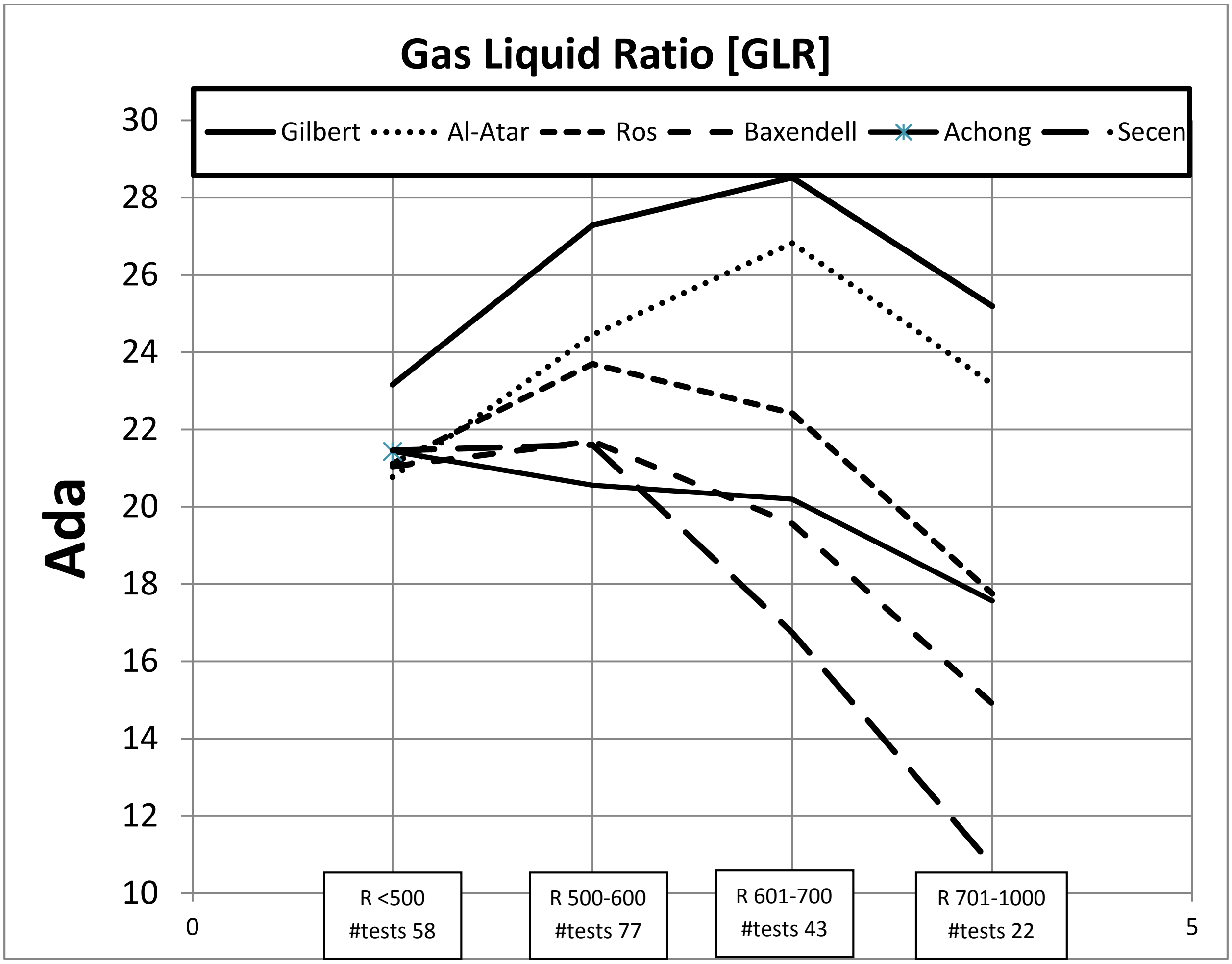

Figure 4 Gas liquid ratio(GLR) ranges to compare tested correlations(R=range)

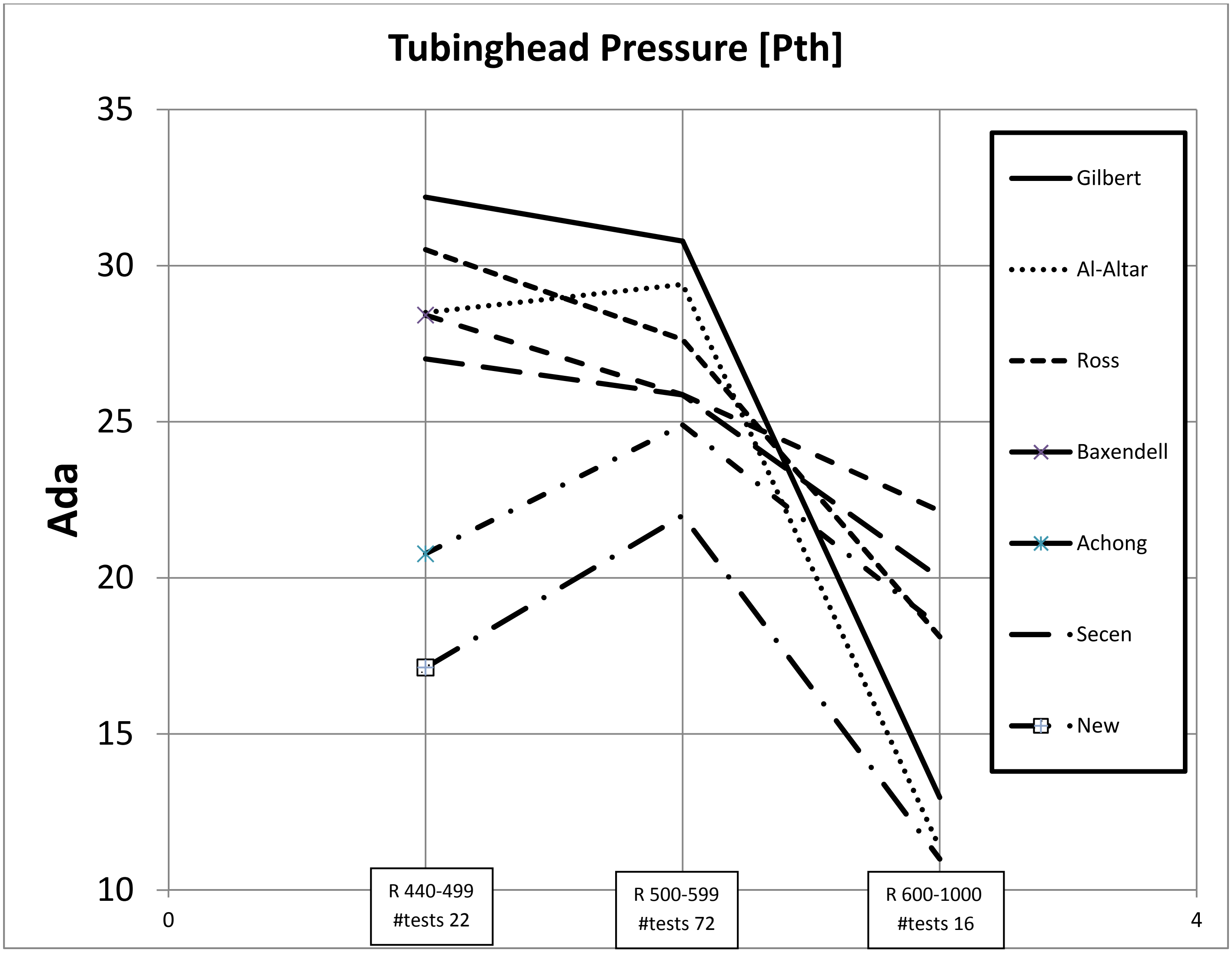

Figure 5 Tubinghead (Pth) ranges to compare tested correlations against new correlation (R=range)

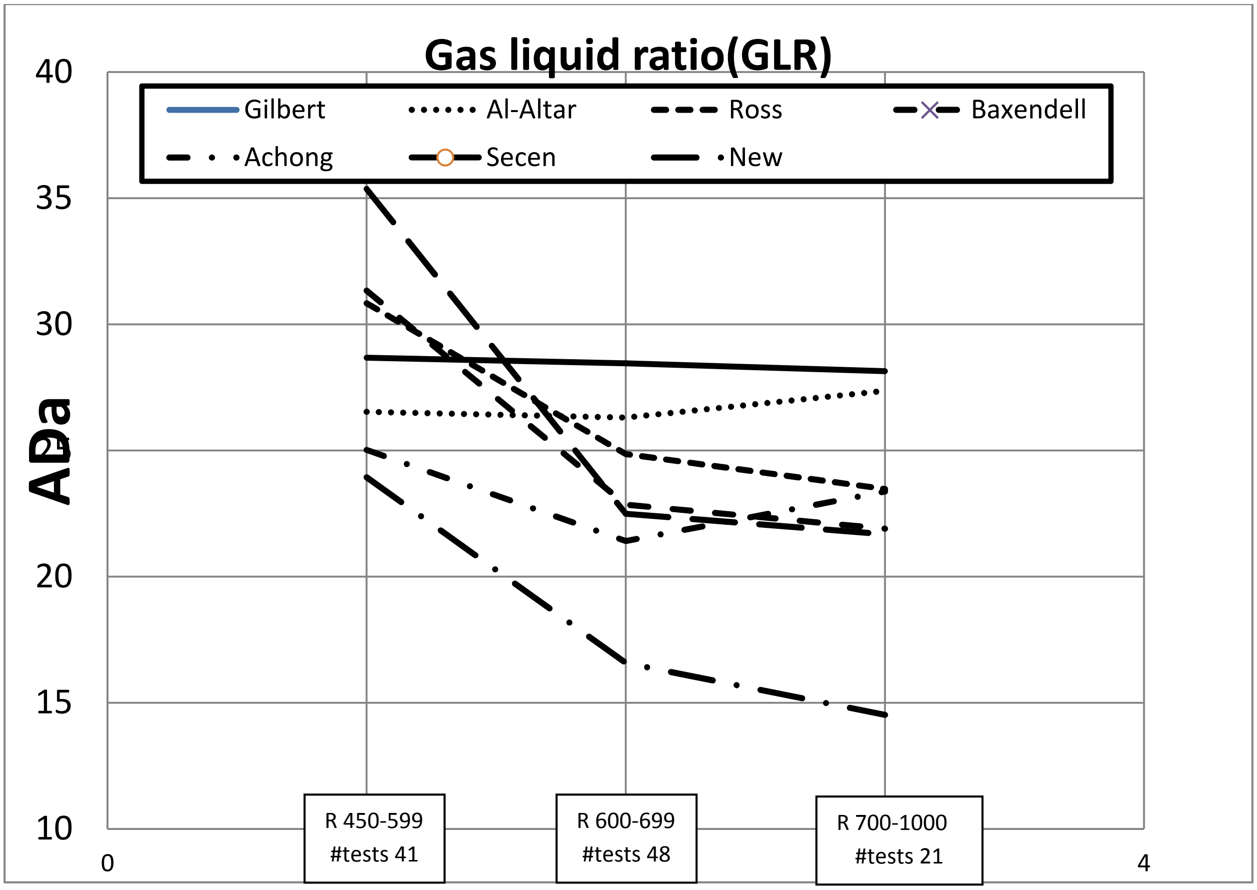

Figure 6- Gas liquid ratio (GLR) ranges to compare tested correlations against new correlation(R=range)

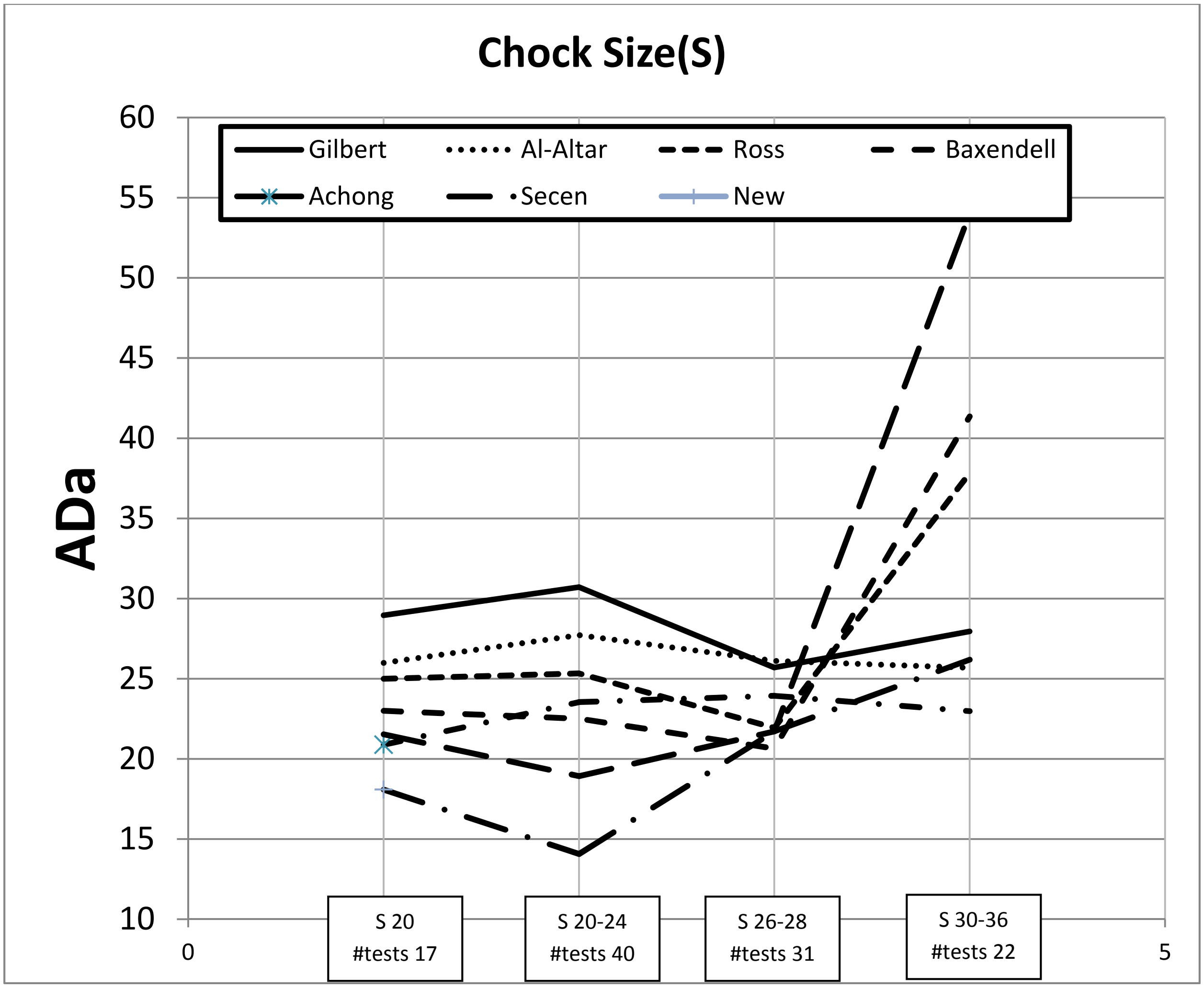

Figure 7 Choke size (S) ranges to compare tested correlations against new correlation (S choke size 1/64")