# Comprehensive Study on Surface Flow Rates/Velocities Determination in Gas Condensate Producing Well through Chokes and Flexible Pipes

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## Abstract

Multiphase flow occurs in almost all producing oil and gas/condensate wells. Wellhead chokes are special equipment that widely used in the petroleum industry to (1) control flow rate, to (2) maintain well allowable, to (3) protect surface equipment, to (4) prevent water and gas coning and to (5) avoid formation damage from excessive drawdown. Gas flow velocity and rate especially through chokes had been studied by numerous investigators, different choke flow models are available from the literature, and they have to be chosen based on the flow regimes, that is, subsonic or sonic flow. Also when the fluid velocity is high, erosion damage occurs and subsequently results in critical flowing condition.

A comprehensive review of these correlations indicated that they are not theoretically rigorous and give inaccurate flow rate for the real conditions. Thus these correlations need to be modified. Al-Attar plotting method also used by seperator test data set to predict flow rate and the method accuracy was discussed. The results of this work are very important in the design and implementation of deliverability tests, pressure transient tests, well control, and long-term well production. These results should encourage the production engineer which works at such condition to utilize the optimum correlations for future practical answers when a lack of available information, time, and calculation capabilities arises.

**Keywords :**Choke Flow Model, Correlation, Flow Velocity, Critical Condition, Gas Flow Rate

## Research Highlights

- Further management, field development and engineering purposes reqiure several optimum methods to predict gas flow rate.
- To calculate wet factor in each part of the reservoir an ANN method is developed which can estimate WF with 95% accuracy.
- all available correlation from Eni, SLB, Halliburton, Texas A&I and Dry gas could be used considering fine-tuning before applications.

## *1. Introduction*

Multiphase flow occurs in almost all producing oil and gas/condensate wells. Every flowing well has some devices to control the flow rate for maintaining sufficient back pressure to prevent formation damage, to protect surface equipment, to prevent water/gas coning, to stabilize the flow rate and to produce the reservoir at the most efficient possible rate.[2] Thus chokes are one of the most important flow controllers in oil and gas producing wells. Accurate modeling of choke performance and selection of optimum choke size is vitally important for a petroleum engineer in testing/clean up operation and production from reservoirs due to high sensitivity of oil and gas production to choke size. Flow through a surface choke can be described as either critical or sub-critical. Critical flow occurs when the velocity through the choke is greater than the sonic velocity of the fluid. *This results in a Mach number of the fluid that is greater than or equal to one*.[5] For fluids with a velocity greater than sonic velocity, any downstream perturbation is unable to propagate upstream and the mass flow rate through the choke is solely a function of the upstream parameters, in other words, in a critical flow region, the mass flow rate reaches a maximum value that is independent of a pressure drop applied across the choke.[3]

Therefore, once critical flow is reached, any disturbance introduced downstream of the choke will have no effect on upstream conditions.Conversely, in sub-critical flow, the flow rate depends on pressure difference across the choke and changes in the downstream pressure affect the upstream pressure. Two main approaches have been proposed for prediction of multiphase flow through chokes can be classified as either analytical or empirical.

The first investigation on gas-liquid two-phase flow through restrictions was performed by Tangren (1949). He presented an analysis of the behavior of an expanding gas-liquid system showing when gas bubbles are added to an incompressible fluid, above a critical flow velocity, the medium becomes incapable of transmitting pressure change upstream against the flow. Gilbert (1954) proposed the first empirical correlation for critical flow in which the flow rate is linearly proportional to the upstream pressure. He used 268 production tests for choke sizes between 6/64” to 18/64” and developed the first empirical correlation.[10] It is the best-known empirical correlation for critical flow. Some researchers revised Gilbert model and developed other equations with modified coefficients. The flow through wellhead restrictions of an offshore oil field in Iran is investigated and several sets of correlations are presented for high flow rate conditions to evaluate the accuracy of available correlations in addition to review of limitations resulted in gas flow velocity, Table-1.

Regarding high flow rate through chokes in studied reservoir the fear of severe damage due to erosion and erosion-corrosion has curtailed production from potentially high-capacity wells.[6] In case of corrosion failures, some control is achieved by the use of corrosion inhibitors. However, at the present time, erosion failures are not controlled, but are being avoided by reduced production. This only reduces revenue from the loss of potential production. A well is drilled, completed, and before putting on production should be cleaned-up and tested, to determine reservoir characterization, deliverability and production potential. The flow path in the well test/ clean-up operation for these fluids from the reservoir to the surface includes: (1) The porous media of the reservoir, (2) The openings in the completion, (3) The production tubing, (4) The wellhead equipment, (5) Flow lines; Flexible pipes till SSV and rigid pipes, and (6) Restrictions. (chokes, separator and etc.)[4]

The fluid flow conditions and the failures created thereof in each part should be considered in the assessment of any potential problem. Unattended failures may be unsafe and detrimental to the personnel working in the near vicinity. Properly scheduled maintenance programs for high-capacity wells to monitor the extent of erosion damage may minimize any potentially dangerous situations.

## *2. Methodology*

In order to evaluate chokes correlations several surface test results were used to illustrate the application of aforementioned correlations in table-1 for choke performance analysis. After calculation of gas flow rate based on those correlations using excel spreadsheet it is obvious that all available correlations in table-2 were inadequate to our data set; it means we should use another correlations to calculate gas flow rate.

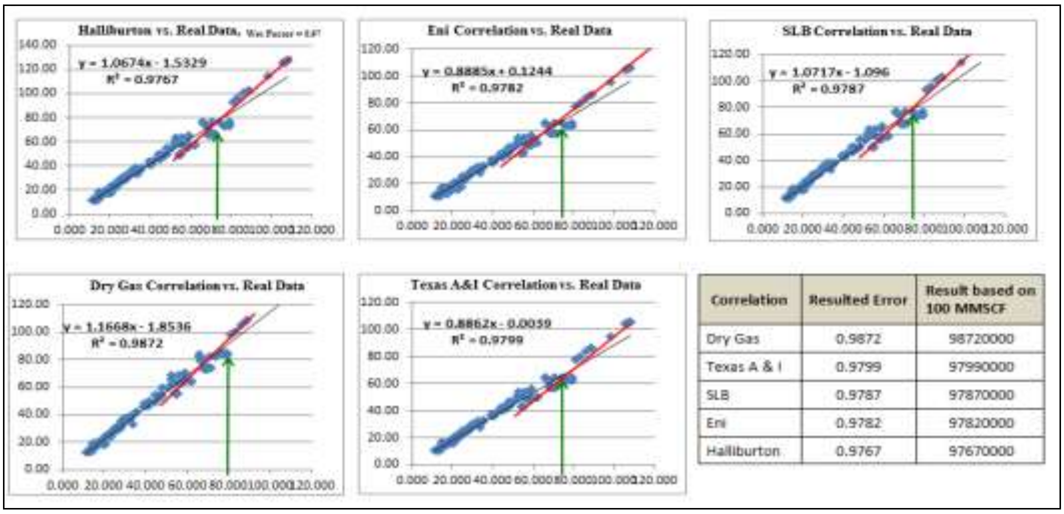
Several institute & services companies use in-house (confidential) correlations for calculate of choke flow rate. We gathered these correlations in table-2. But due to confidential issues there are simbols instead of coefficients values.

In AL-Attar plotting technique data wil be plotted in $(P_{up} - P_{ds})/Q$ vs. GOR in a log-log plot format. We use this method to our data set for each choke sizes separately and also for all data togather, but the result was not adequate and a unique results was not determined.

We should consider that in real well testing/clean-up operation, gas flow rate have to be determined and then erosional velocity ,equation-2 in table-3, as a restriction factor on surface facility would be calculated. The available equations and explanation to calculate gas velocity are presented in Table-3.

Reservoir and flowing pressure are of important parameters which affected gas velocity in cofflex pipe (cofflex OD is 4-1/16”, before passing of flow from choke). In year 2002 to 2009 when the reservoir average pressure in target field was between 5400 to 4600 psi, in the case of testing/clean-up operation, responsible companies for testing services could flow wells upto 150 MMSCFD without any risks due to critical erosion velocity restrictions. But after several years when the reservoir depleted and average reservoir pressure fall in the rage of 3300 to 4200 psi, wells could net be flowed more than 100 MMSCFD using cofflex pipe 4-1/16” for more explanation please look at table-4.

## *3. Tables & Figures*



| Correlation | Resulted Error | Result based on 100 MMSCF |
|---|---|---|
| Dry Gas | 0.9872 | 98720000 |
| Texas A & I | 0.9799 | 97990000 |
| SLB | 0.9787 | 97870000 |
| Eni | 0.9782 | 97820000 |
| Halliburton | 0.9767 | 97670000 |

**Fig.1. Correlation's error comparison**

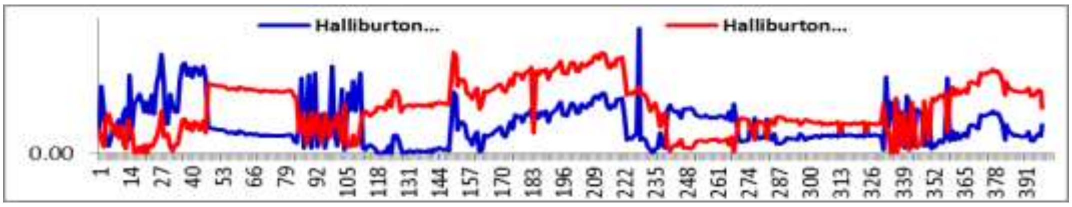


**Fig.2. Halliburton Correlation comparison of WF 0.98 (blue line) and 0.88 (red line)**

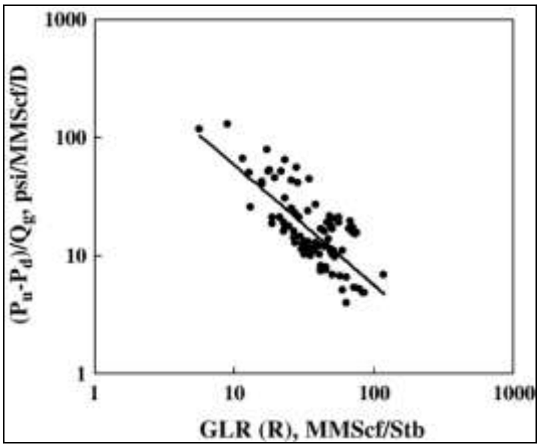


**Figure 3. Al Attar plotting technique applied to all data points**

**Table 1. Choke Correlations**

| | **$P_{upstream} = B.\ Q_L^D.\ GLR^C/d_{Choke}^A$** | **Empirical Coefficients [12]** | | | |
|---|---|---|---|---|---|
| | Correlation | A | B | C | D |
| 1 | Gilbert (1954) | 1.89 | 10.00 | 0.546 | 1.00 |
| 2 | Baxendell (1957) | 1.93 | 9.56 | 0.546 | 1.00 |
| 3 | Achong (1961) | 1.88 | 3.82 | 0.65 | 1.00 |
| 4 | Ros (1960) | 2.00 | 17.40 | 0.50 | 1.00 |
| 5 | Aussens | 1.97 | 3.89 | 0.68 | 1.00 |
| 6 | Corpoven (oil/ volatile oil) | 1.9523 | 8.255814 | 0.501022 | 1.0645 |
| 7 | Corpoven (gas/ gas condensate) | 1.814859 | 7.700537 | 0.595821 | 0.962028 |
| | **$Q_L = A.\ P_{wh}.S^B.\ (1\text{-}BSW/100)^D/GLR^C$** | **Empirical Coefficients [1]** | | | |
| | Correlation | A | B | C | D |
| 1 | Gilbert | 0.10 | 1.89 | 0.546 | 0.00 |
| 2 | Ros | 0.574 | 2.00 | 0.50 | 0.00 |
| 3 | Baxendell | 0.1046 | 1.93 | 0.546 | 0.00 |
| 4 | Achong | 0.2618 | 1.88 | 0.65 | 0.00 |
| 5 | Iranian Model (Mech. Sci., 3, 43–47, 2012) | 0.0328 | 2.275 | 0.586 | 0.00 |
| 6 | Iranian Model (Mech. Sci., 3, 43–47, 2012) | 0.0328 | 2.151 | 0.5154 | 0.52965 |
| | **$Q_L = \left[P_{up}.\ (64.D_{bean})^c/(a.GLR^b)\right]^{1/d}$** | **Empirical Coefficients [13]** | | | |
| | Correlation | A | b | c | d |
| 1 | Achong | 3.82 | 0.65 | 1.88 | 1.00 |
| 2 | Baxendell | 9.56 | 0.546 | 1.93 | 1.00 |
| 3 | Gilbert | 10.00 | 0.546 | 1.89 | 1.00 |

| | | | | | |
|---|---|---|---|---|---|
| 4 | Pilehvari (1981) | 46.67 | 0.313 | 2.11 | 1.00 |
| 5 | Ros | 17.4 | 0.50 | 2.00 | 1.00 |
| 6 | Owolabi et al | 35.72 | 0.29 | 1.83 | 1.00 |
| | **$Q_g = a.\Delta P.S^b.GLR^c$** | **Empirical Coefficients [1]** | | | |
| | Correlation | A | b | c | d |
| 1 | H. Al-Attar (2008) | 1/29,653.3 | 1.15537 | 0.84695 | - |
| 2 | Iranian Model (2011, SPE 145576) | 1/9,350 | 1.9 | 0.65 | - |

**Table 2. Practical Correlations**

| **Correlations of valid worldwide services/operator companies and research institutes [12]** | |
|---|---|
| **Company** | **Correlation** |
| SLB | $Q_g = (a_1\ C.S.^2 + a_2\ C.S. + a_3) * WHP/ (S.G.*(WHT+460))^{a}{}_{4} /1000$ |
| Halliburton | $Q_g = [(C.S./64)^{b}{}_{1} * b_2 * b_3 * (WHP+b_4)]/ (S.G.*(WHT+460))^{b}{}_{5} * (\text{wet factor}/1000)$ |
| Eni | $Q_g = c_1 * WHP/ (S.G.*(WHT+460))^{c}{}_{2} /1000$ |
| Texas A & I | $Q_g = d_1 * Cd * A * WHP/ (S.G.*(WHT+460))^{d}{}_{2} /1000$ |
| Dry Gas Correlation | $Q_g = e_1 * (WHP+e_2) * (C.S.)^{e}{}_{3}/1000$ |
| *Due to confidentiality of the correlations constant coefficient values for all correlation are not indicated. | |

**Table 3. Velocity Calculations**

| **Erosional Velocity equations and correlations** | |
|---|---|
| **Company** | **Correlation** |
| Erosion Velocity | $V_e\ (ft/s) = C/ (\rho_m)^{0.5}$<br>$\rho_m = (12409\ S_L.P + 2.7\ R.S_G.P) / (198.7\ P + R.T.Z)$ |
| Industry experience to date indicates that for solids-free fluids values of c = 100 for continuous service and c = 125 for intermittent service are conservative. For solids-free fluids where corrosion is not anticipated or when corrosion is controlled by inhibition or by employing corrosion resistant alloys, values of c = 150 to 200 may be used for continuous service; values up to 250 have been used successfully for intermittent service. If solids production is anticipated, fluid velocities should be significantly reduced, Different values of *"c" may be used where specific application studies have shown them to be appropriate. | |
| Effluent Velocity limit in Cofflex | $V_g\ (ft/s) = 60\ Z.Q_g.\ T/ (d_1^2\ P)$ |

**Table 4. Reservoir or Wellhead Flowing Pressur effect on Gas Flow Velocity in Cofflex Pipes**

| Well No. | current WHP psi | after 5 years WHP psi | Qg, Total mmscfd | after 5 years Erosion velocity (ft/s) | current Erosion velocity (ft/s) |
|---|---|---|---|---|---|
| 1 | 719.0 | 219.00 | 15.00 | 129.95 | 39.58 |
| 2 | 1214.30 | 714.30 | 33.66 | 90.23 | 53.08 |
| 3 | 3,192.6 | 2692.60 | 102.92 | 80.70 | 68.06 |
| 4 | 3,511.2 | 3011.16 | 111.92 | 77.91 | 66.81 |
| 5 | 3,544.1 | 3044.10 | 112.74 | 77.90 | 66.91 |

**Table 5. Case Processing Summary – SPSS Output**

| | | N | Percent |
|---|---|---|---|
| Sample | Training | 183 | 99.5% |
| | Testing | 1 | .5% |
| Valid, Excluded, Total | | 184, 85, 269 | 100.0% |

**Table 6. Neural Network Information – SPSS Output**

| | | |
|---|---|---|
| Input Layer | Factors | WHP, WHT, WHPDCP, SGg, SGo, BSW |
| | Covariates (1), Number of Unitsa | Choke Size, 582 |
| | Rescaling Method for Covariates | Adjusted normalized |
| Hidden Layer(s) | Number of Hidden Layers, Number of Units in Hidden Layer 1a | 1, 17 |
| | Activation Function | Hyperbolic tangent |
| Output Layer | Dependent Variables (1), Number of Units | Wet Factor, 174 |
| | Activation Function, Error Function | Softmax, Cross-entropy |

## *4. Results and Discussion*

We calculate gas flow rate using all 5 available validated correlation in table-2, and found that the best correlation in target Iranian Offshore Reservoir is "Dry Gas Correlation". We should consider based on calculated error, all are compatible to the target field flow rate data. It could be pointed out that we divided separator test data set into two categories, below 80 MMSCFD & 80 to 105 MMSCFD. We found that correlation inaccuracies increase in higher flow rates, between 80 to 105 MMSCFD.

It should be considered the important factor in using one of these correlations which is Halliburton correlation’s "wet factor".

This parameter is the choke efficiency property regardless any reservoir or completion effects. To optimize and fine tune this factor value use in all wells of the reservoir, Regarding all 399 tests data results, back calculation based on Halliburton correlation was done and wet factor separately calculated for each test data set, then it is averaged and the tuned value was determined 0.98. Fig-2 shows that, error of WF = 0.88 is much more than WF = 0.98.

In addition to this simple calculation we generate an actively more valid correlation for calculation of wet factor based on non-linear regression (NLR) method and artificial neural network (ANN) algorithm. Based on different forms of correlation to generate a proper correlation between wet factor and other parameters using NLR method, but the results was not compatible and we could not generate a correlation. In the use of generate a correlation or logic relations we attempt ANN method for this aim and the results was excellent.

NLR was not used because of inaccuracy. The results that calculation was based on SPSS software is shown in Table 5 & 6.

## *5. Conclusions*

1. We used several methods such as NLR, ANN , Al-Attar plot and available correlations and validate them to predict gas flow rate for further management, field development and engineering purposes.
2. Based on results in this study, *wet factor* in Halliburton correlation ranges from 0.77 to 1.13 with average value of 0.98.
3. In the case of using halliburton correlation to calculate wet factor in each sections of the reservoir an ANN method is developed which can estimate WF with 95% accuracy.
4. Error analysis indicates that *dry gas correlation* is the best correlation in target wells.
5. Based on 399 test separator data and available correlations, all correlation could be used considering fine-tuning before applications.

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## *Nomenclature*

| | |
|---|---|
| Choke size exponent | CS, S, $D_{bean}$, $d_{choke}$ |
| Liquid–Specific gravity | $S_L$ |
| Gas–Specific gravity | $S_G$ |
| Cofflex ID | $d_1$ |
| Number of data points | n |
| Empirical constant, Wet Factor | WF |
| Upstream (wellhead) pressure, psia | $P_{up}$ |
| Downstream pressure from choke, psia | $P_{ds}$ |
| Pressure differential across choke, psia | $\Delta P$ |
| Gross liquid rate, Stb/D | Q |
| Gas–liquid ratio, MScf/Stb | R, GOR |
| Wellhead flowing temperature, deg. F | WHT |
| Artificial Neural Network | ANN |

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