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# New Inflow Performance Relationship for Gas Condensate Reservoirs

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**ABSTRACT:** Predicting the relationship between the flow rate and the pressure drop performance in the reservoir is very important for continuous production optimization in the field. The inflow performance relationship (IPR) describes the relationship between the flow rate of the well (q) and the following pressure of that well (Pwf). Different inflow performance relationship correlations exist today in the petroleum industry with the most commonly used models are that of Vogel and Fetkovich. Gas condensate reservoirs are primarily gas reservoir but when reservoir pressure declines below dew point pressure the liquid begins produced. The goal of this work is to develop a new model to predict the inflow performance relationship curve for gas condensate reservoirs. This new correlation was developed using about 200 data points were collected from different Middle East gas condensate reservoirs. The development model was tested by comparing its accuracy with that of the most common inflow performance relationship models such as Vogel, Fetkovich and Wiggins models. The results of this comparison showed that the new developed model gave the best accuracy with an average absolute error of 11.38% while the other common model, Vogel, Fetkovich and Wiggins, gave an average absolute error of 69.39%, 22.65% and 45.75% respectively.

**KEYWORDS:** IPR, model, gas condensate reservoir, relationship.

## 1 INTRODUCTION

Prediction the relationship between flow rate and pressure drop performance in the reservoir is very important for production optimization in the field. If the wellbore pressure is equal to the reservoir pressure, there can be no inflow. If the wellbore pressure is zero, the inflow would be the maximum possible Absolute Open Flow (AOF). For intermediate wellbore pressures the inflow will vary. For each reservoir, there will be a unique relationship between the inflow rate and wellbore pressure. In single phase flow, the inflow performance curve is a straight line but when gas is moving in the reservoir, at a pressure below the bubble point, this is not a linear relationship as shown in Fig. (1).

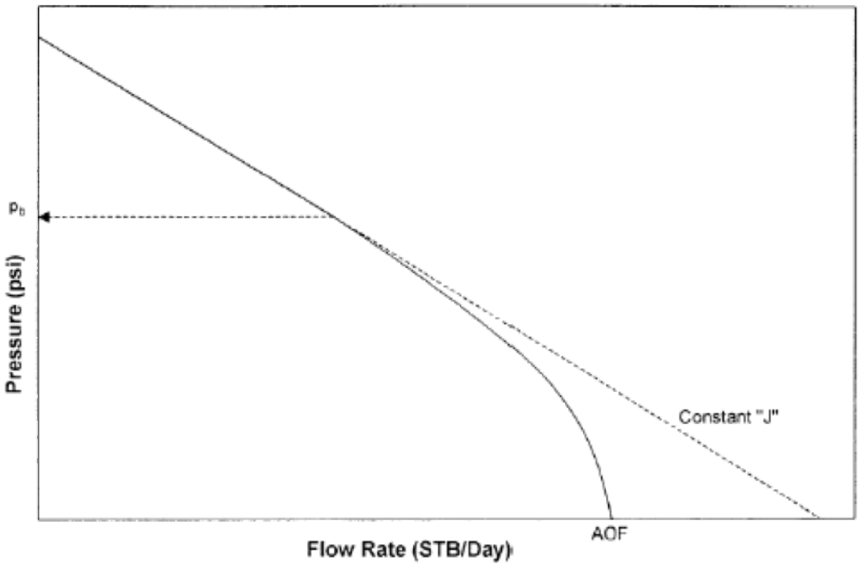


***Fig. 1. The inflow performance curve***

Many IPR correlations addressed the curvature in Fig. (1) of the inflow performance curves in case of solution gas drive oil reservoirs in which the babble point pressure is the initial reservoir pressure.

Vogel (1968) [6] developed inflow performance relationship (IPR) correlation by using a computer program based on Weller's assumptions and twenty-one reservoir data sets to develop an inflow performance relationship correlation as:

$$\frac{q_o}{q_{omax}} = 1 - 0.2\left[\frac{P_{wf}}{P_r}\right] - 0.8\left[\frac{P_{wf}}{P_r}\right]^2$$

Fig. (2) presented the Vogel plot illustrating the liquid (oil), gas (dry gas), and solution gas-drive cases. Vogel's correlation gave a good match with the actual well inflow performance at early stages of production but deviates at later stages of the reservoir life. Vogel correlation didn't include IPR curves for wells with damage or high viscosity.

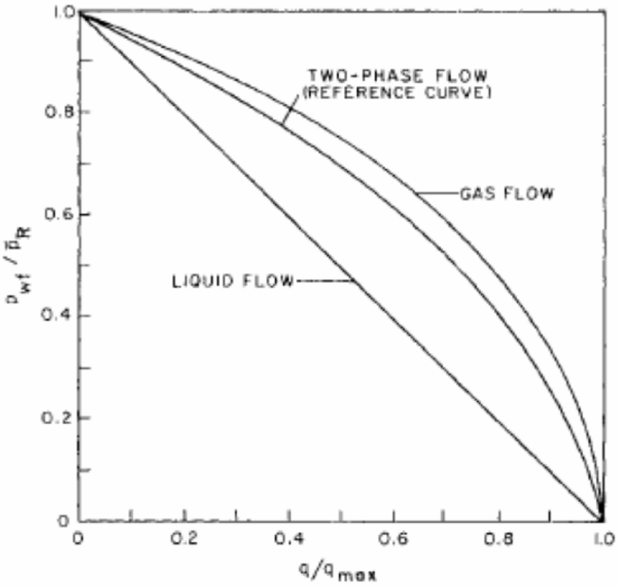


***Fig. 2. IPR schematic plot for single phase oil, single phase gas and solution gas drive system [6]***

Fetkovitch (1973) [3] developed an empirical equation based on two correlation parameters, maximum oil flow rate and deliverability exponent for Fetkovich. This empirical equation is given in the following form:

$$\frac{q_o}{q_{omax}} = \left[1 - \left(\frac{P_{wf}}{P_r}\right)^2\right]^n$$

Fig. (3) is a rationale for the preference of the above equation. To apply the above correlation, well measurements must be performed during at least two stable flow conditions to determine the value of deliverability exponent.

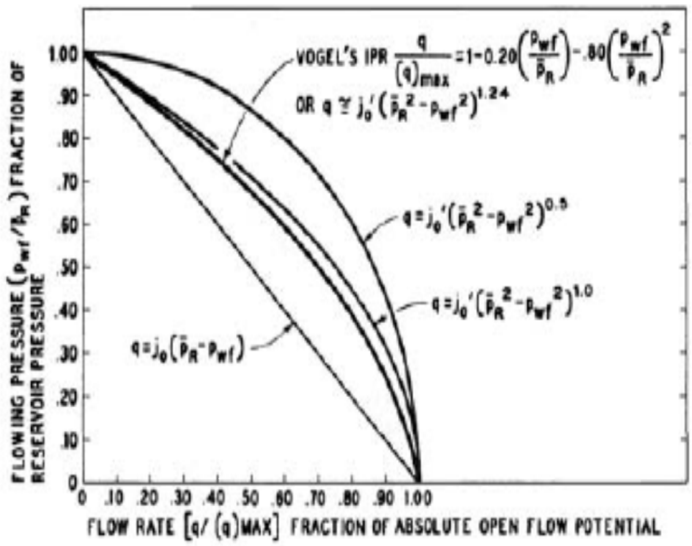


*Fig. 3. IPR for various flow equations [3]*

Klins and Majher (1992) [4] developed an inflow performance relationship correlation that takes into account the change in bubble-point pressure and reservoir pressure based on Vogel's work. This correlation is given by the following

$$\frac{q_o}{q_{omax}} = 1 - 0.295\left[\frac{P_{wf}}{P_r}\right] - 0.705\left[\frac{P_{wf}}{P_r}\right]^N$$

Where

$$N = \left(0.28 + 0.72\frac{P_r}{P_b}\right)(1.235 + 0.001P_b)$$

Wiggins (1993) [7] developed the following generalized empirical three phase IPR similar to Vogel's correlation based on his developed analytical model in 1991:

$$\frac{q_o}{q_{omax}} = 1 - 0.519167\left[\frac{P_{wf}}{P_r}\right] - 0.481092\left[\frac{P_{wf}}{P_r}\right]^2$$

Wiggins, et al. (1991, 1992) found that the main reservoir parameter that plays a major role in the inflow performance curve is the oil mobility function. The major problem in applying this IPR is its requirement for the mobility derivatives as a function of reservoir pressure, which is very difficult in practice. Therefore, in 1993 Wiggins developed an empirical IPR correlation from this analytical IPR model by assuming a third degree polynomial relationship between the oil mobility function and reservoir pressure. Wiggins, et al. also presented plots of the oil mobility as a function of reservoir pressure taken at various flow rates.

Sukarno and Wisnogroho (1995) [5] developed an IPR correlation based on simulation results that attempts to account for the flow efficiency variation caused by rate-dependent skin. This equation is given in the following form:

$$\frac{q_o}{q_{omax}} = FE\left[1 - 0.1489\frac{P_{wf}}{P_r} - 0.4416\left(\frac{P_{wf}}{P_r}\right)^2 - 0.4093\left(\frac{P_{wf}}{P_r}\right)^3\right]$$

Where

$$FE = a_0 + a_1\frac{P_{wf}}{P_r} + a_2\left(\frac{P_{wf}}{P_r}\right)^2 + a_3\left(\frac{P_{wf}}{P_r}\right)^3$$

Fattah et al. (2012) [2] developed a new model to predict the IPR curve by using 47 actual field cases in addition to several simulated tests. This new correlation describes the behavior of the oil mobility as a function of the average reservoir pressure.

## 2 DATA ACQUISITION FOR MODELLING

About 200 data points were collected from different Middle East gas condensate fields which are being used in this study to evaluate the inflow performance relationship models and for developing the new model. The data ranges and description of these data are shown in Table (1).

*Table 1. The reservoir, rock and fluid properties*

| Reservoir, rock and fluid properties | Range | Unit |
|---|---|---|
| **Pressure** | 2767 - 6193 | Psia |
| **Temperature** | 178 - 303 | F |
| **API** | 47.8 – 66.3 | API |
| **Gas oil ratio** | 7160 - 10157 | SCF/STB |

## 3 DEVELOPED NEW MODEL

The objective of this work is to develop a simple and consistent method to correlate IPR trends for gas condensate reservoir systems without direct knowledge of the distributions of gas oil ratio and the saturation profiles .The IPR curves for gas-condensate reservoirs were generated using the same procedure that Vogel proposed for solution gas-drive reservoirs. The parameters of new model are determined using a non-linear optimization routine, specifically the "Solver" modules implemented in Microsoft Excel. The new model was written as

$$\frac{q_o}{q_{omax}} = 1 - 1.081701\left[\frac{P_{wf}}{P_r}\right] - 1 \times 10^{-4}\left[\frac{P_{wf}}{P_r}\right]^2$$

The actual data and the data results from new model, Vogel, Fetkovich and Wiggins models are plotted to gather in Figures (4) to (7). Fig. (2) shows that the crossplot of data results from new developed model almost fall on the 45° line implying excellent correlation. The crossplot of Vogel and Wiggins models above the 45° line while the crossplot of Fetkovech model below the 45° line as shown in Figures (4) to (7).

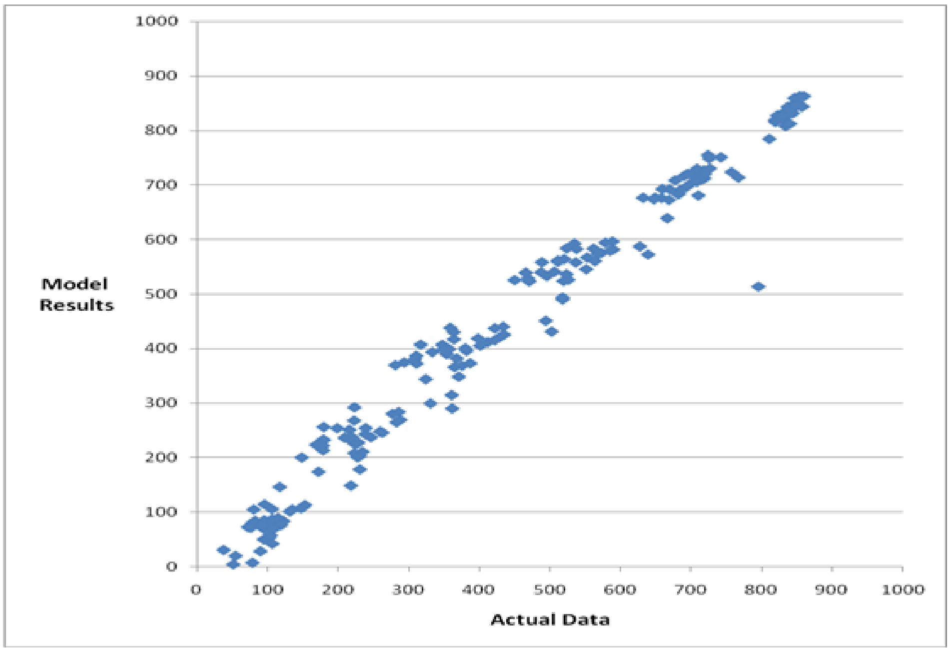


*Fig. 4. Crossplot of actual data against predicted data from new model*

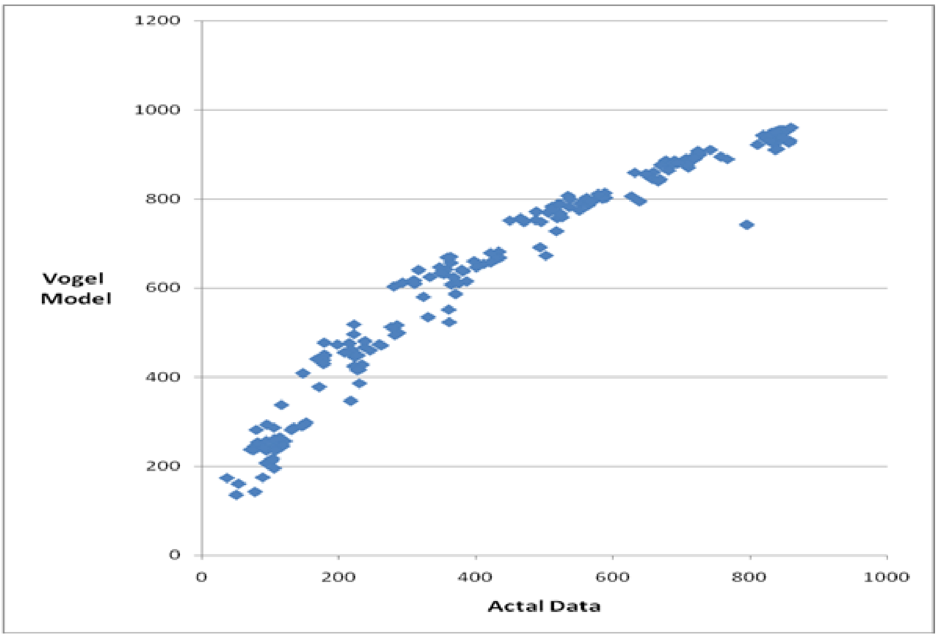


*Fig. 5. Crossplot of actual data against predicted data from Vogel model*

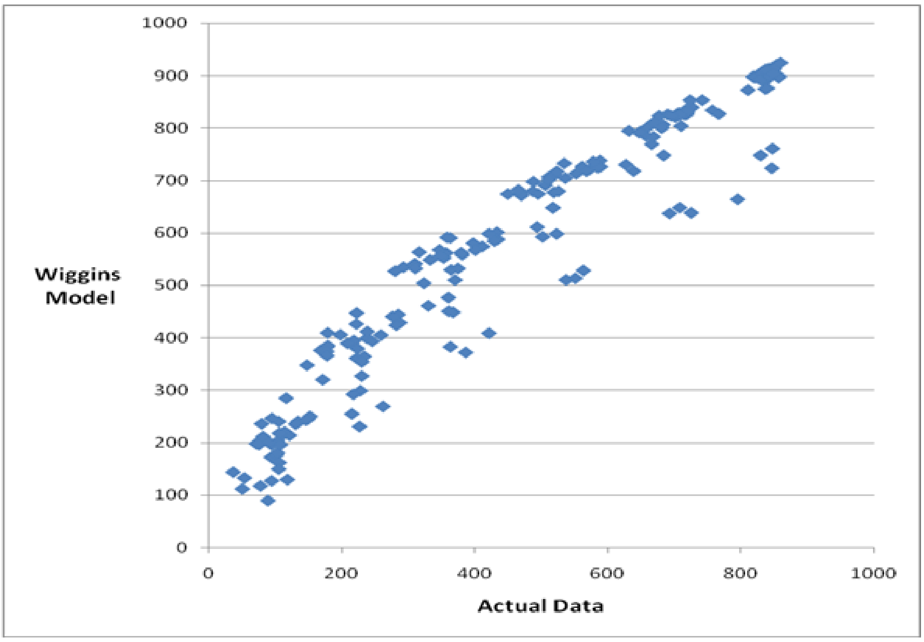


*Fig. 6. Crossplot of actual data against predicted data from Wiggins model*

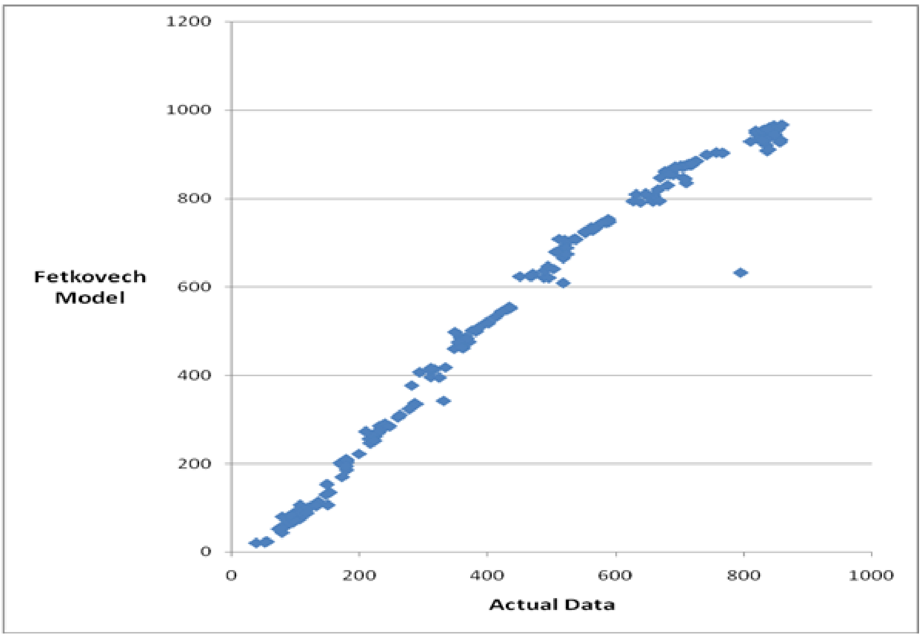


*Fig. 7. Crossplot of actual data against predicted data from Fetkovech model*

## 4 VALIDATION OF THE NEW INFLOW PERFORMANCE RELATIONSHIP (IPR) MODEL

To verify and validate the new developed IPR model, the new model was tested by comparing its accuracy with that of the most common IPR models such as Vogel, Fetkovich and Wiggins models.

The average absolute errors percent between the actual flow-rate data and the calculated rate for the four IPR methods that used in this study are shown in Fig. (8) for the comparison. It is clear from this Fig. that the new developed IPR model has the lowest average absolute error percent that is 11.38%, while the average absolute error percent for Fetkovich method is 22.65 %. The other methods have average absolute errors percent ranging from 45.75 to 69 .39% for Wiggins and Vogel, respectively.

Table (2) presents a summary of the average absolute errors percent that was obtained for each method. As indicated, the method of the new developed IPR model always provided the lowest value of the total average absolute error percent in comparison with that of other models.

*Table 2. The reservoir, rock and fluid properties*

| Model | New model | Vogel | Fetkovech | Wiggins |
|---|---|---|---|---|
| Average Error % | 11.385172 | 69.391355 | 22.6466525 | 45.7483122 |

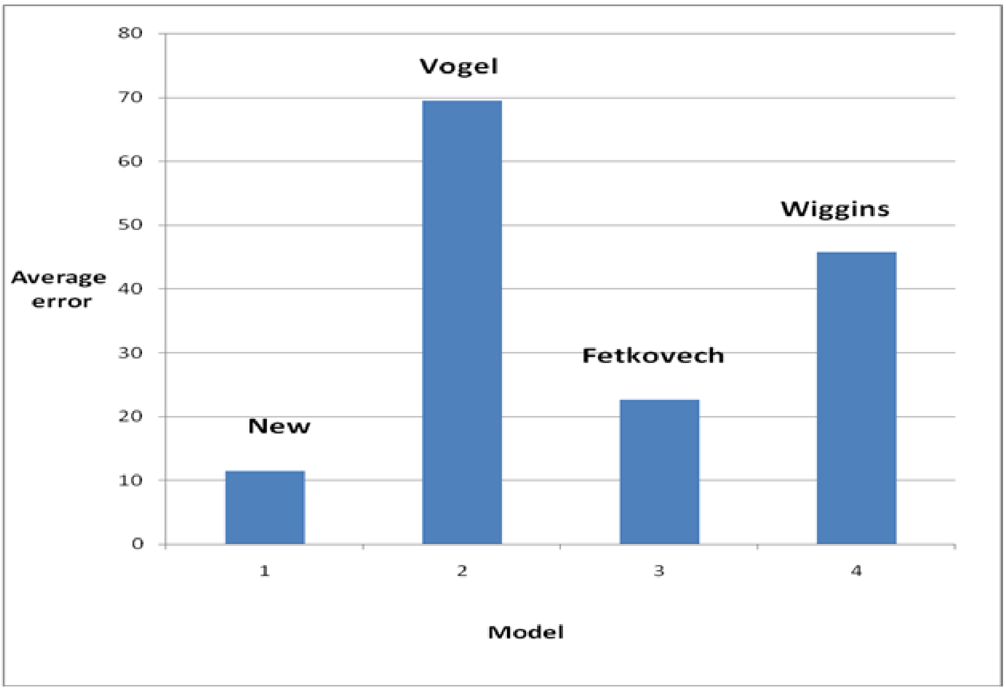


*Fig. 8. The average absolute error analysis*

## 5 CONCLUSIONS

- The new IPR model was developed to construct and predict the IPR curve for gas condensate reservoirs.
- The validity of the new IPR model was tested in comparison with the behavior of the most common methods that are used in the industry. The results of this validation showed that the new IPR model ranked the first model that succeeded to predict the behavior of the IPR curve while the other models of Fetkovich, Wiggins and Vogel ranked the second, the third and the forth respectively.
- The new IPR model requires one test point to estimate the maximum flow rate.

## NOMENCLATURES

$n$ = Deliverability exponent for Fetkovich, dimensionless
$Pb$ = Bubble Point Pressure, psia
$Pr$ = Average reservoir pressure, psia
$Pwf$ = Bottom hole flowing pressure, psia
$q_o$ = Oil flow rate, STB/D
$qom$ = Maximum oil flow rate, STB/D

## References

[1] Ahmed,Tarek:" Advanced reservoir engineering", Elsevier Inc ,.Gulf Professional Publishing, 2005.

[2] Fattah, K. A., El-Banbi, H. A., and El-Tayab, A.:"New Inflow Performance Relationship for Solution Gas Drive Oil Reservoirs", Oil and Gas Business, 2012.

[3] Fetkovich M.J.:" The isochronal testing of oil wells", SPE Paper 4529 presented at the Fall Meeting of the Society of Petroleum Engineers of AIME, Las Vegas, NV ,Sep. 30-Oct. 3, 1973.

[4] Klins M.A., Majher M.W.:" Inflow Performance relationships for damaged or improved wells producing under solution-gas drive", SPE paper 19852, Journal of Petroleum Technology, 1992, Vol. 44, Num. 12, pp. 1357 - 1363.

[5] Sukarno P., Wisnogroho A.:"Generalized two-phase IPR curve equation under influence of non-linear flow efficiency", Proc., Soc of Indonesian Petroleum Engineers Production Optimization Intl. Symposium, 1995, Bandung, Indonesia, pp. 31 - 3.

[6] Vogel J.V.:" Inflow performance relationships for solution gas drive wells", Journal of Petroleum Technology, 1968, Vol. 20, Num. 1, pp. 83 – 92. (SPE Paper1476). DOI: 10.2118/1476-PA

[7] Wiggins M.L.:"Generalized inflow performance relationships for three-phase flow", SPE Paper 25458 presented at the SPE Production Operations Symposium ,Oklahoma City, OK, March 21-23 1993. DOI: 10.2118/25458-MS.