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Modelling gas condensate viscosity below the dew point using Fuzzy Logic approach.

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Background and Motivation

- Increasing demand for energy resources, global warming and greenhouse effects motivate the development of gas condensate reservoirs as a cleaner source of energy.
- Gas condensate reservoirs are valuable source of hydrocarbon that play important role in global energy market.

Problem Statement

In gas condensate reservoirs:

- Condensate liquid evolves from the gas phase as pressure decreases to below the dew point due to production, see Fig. 1 phase diagram.

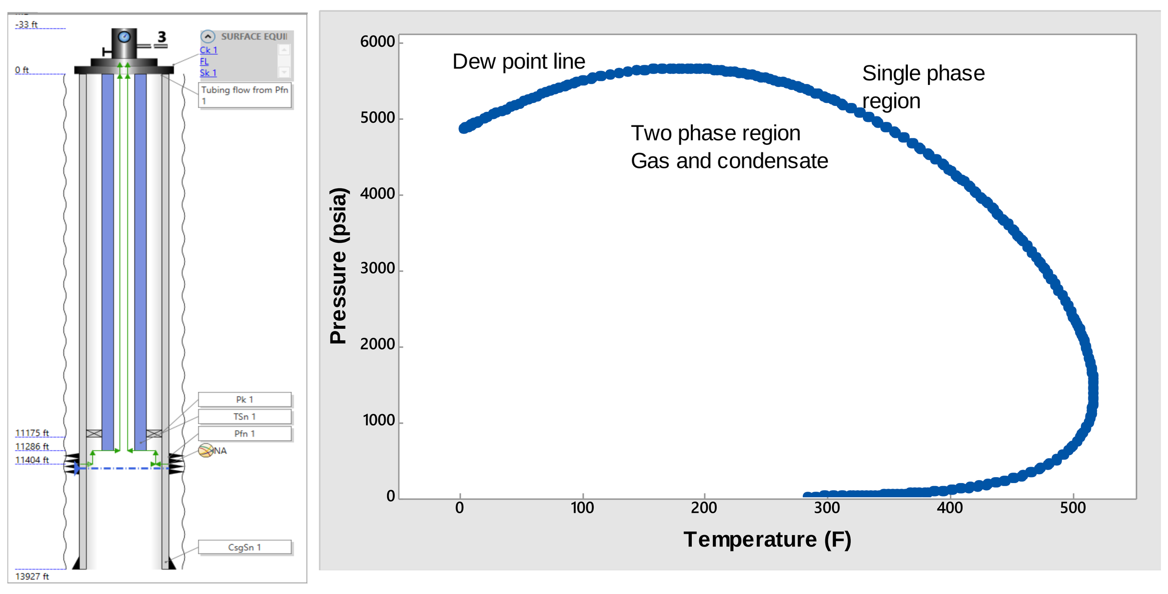


Fig. 1. Reservoir phase diagram of a gas condensate vertical well.

- Condensation is in vicinity of the wellbore and reduces deliverability of the well significantly.
- Accurate model is required for accurate prediction of well deliverability and production strategy.

Research Objectives

- Better modelling of PVT properties "condensate viscosity, using smart approaches.
- Propose set of equations for prediction of condensate viscosity below the dew point.
- Optimize production profile by implementing developed models in gas and condensate flow rate equation in future studies.

Why Viscosity?

- Condensate viscosity is a governing parameter in estimation of a well production rate.

$$Q_g = C\int_{P_{wf}}^{p}\left(\frac{k_{rg}}{B_{gd}\boldsymbol{\mu_g}} + \frac{k_{ro}}{B_o\boldsymbol{\mu_c}}R_s\right)dp$$

$$Q_g = f(Krg, Kro, Bg, \boldsymbol{\mu_g}, B_o, \boldsymbol{\mu_c}, Rs)$$

$$\boldsymbol{\mu_c = f(P, T, Rs)}$$

Data driven model

Property	Min	Max	Median
Pressure, psia	37.7	10982	3663
Temperature, °F	86	338	176
Solution GOR, scf/STB	41.7	13496	3628
Condensate viscosity, (cp)	0.0404	0.982	0.232

Table 1. Properties of gas condensate data bank used in this study.

- The data divided to two parts:

Fuzzy modelling of viscosity

- Fuzzy deals with vagueness, impression and uncertainty in a system.

Which Fuzzy Inference System (FIS)?

Takagi-Sugeno-Kang (TSK)

- Computationally efficient.
- Work well with optimization methods.
- Well-suited to mathematical analysis.

TSK Models Development

General Rule: If Input 1 is x and Input 2 is y, then Output is $z = ax + by + c$

Step 1 Fuzzy Clustering, K-mean clustering

- Optimum number of clusters were determined using (Calinski and Harabasz, (1974):

$$VRC_c = \frac{SS_B}{SS_W} \times \frac{(N-c)}{(c-1)}$$

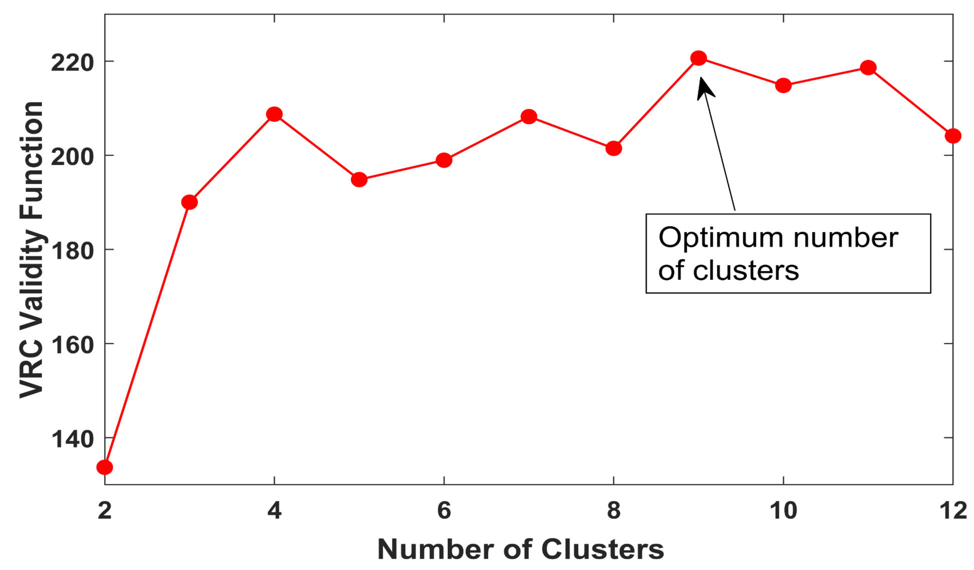


Fig. 2. Cluster validity function VRC_c, for condensate viscosity input data

Step 2 Setting up membership function, Gaussian MF

- Gaussian membership function:

$$\mu_{Ai}(v_i) = exp\left(-\frac{(v_i - c_i)^2}{2\sigma_i^2}\right)$$

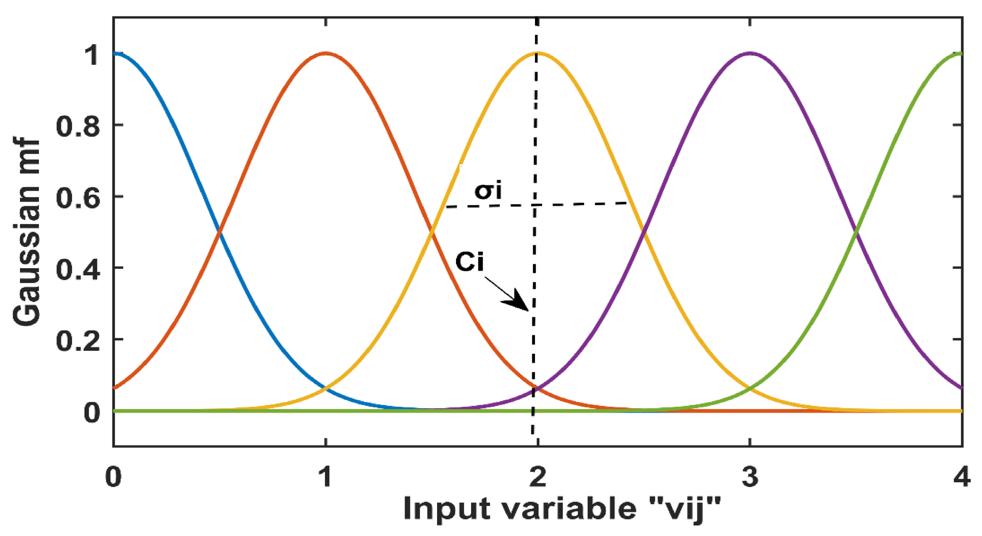


Fig. 3. Gaussian membership function used for detecting fuzzy clusters.

Step 3 Parameter estimation, least square method to find (a, b and c) in $z = ax + by + c$

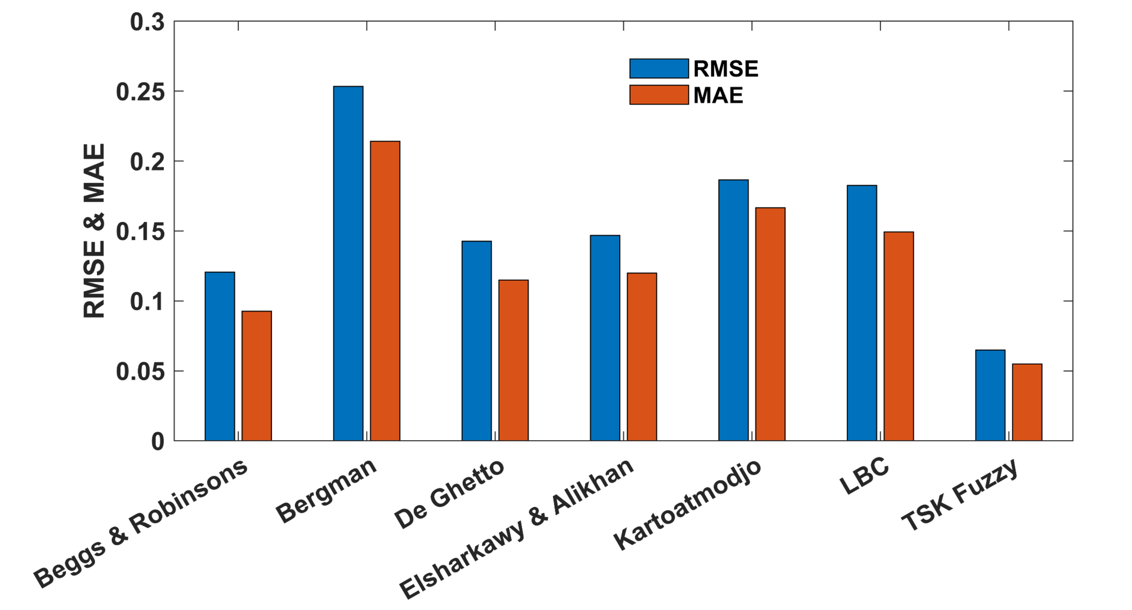
- The performance of the developed fuzzy model compared against six well known gas-saturated-oil viscosity correlations.

Results and Discussion

- 9 condensate liquid viscosity correlations proposed. An example is:

if $6526 \le P \le 10900$ and $86 \le T \le 270$ and $5425 \le Rs \le 6101$ then

$$\mu_c = -0.0063P + 0.0025T \pm 0.0452Rs + 0.0032$$



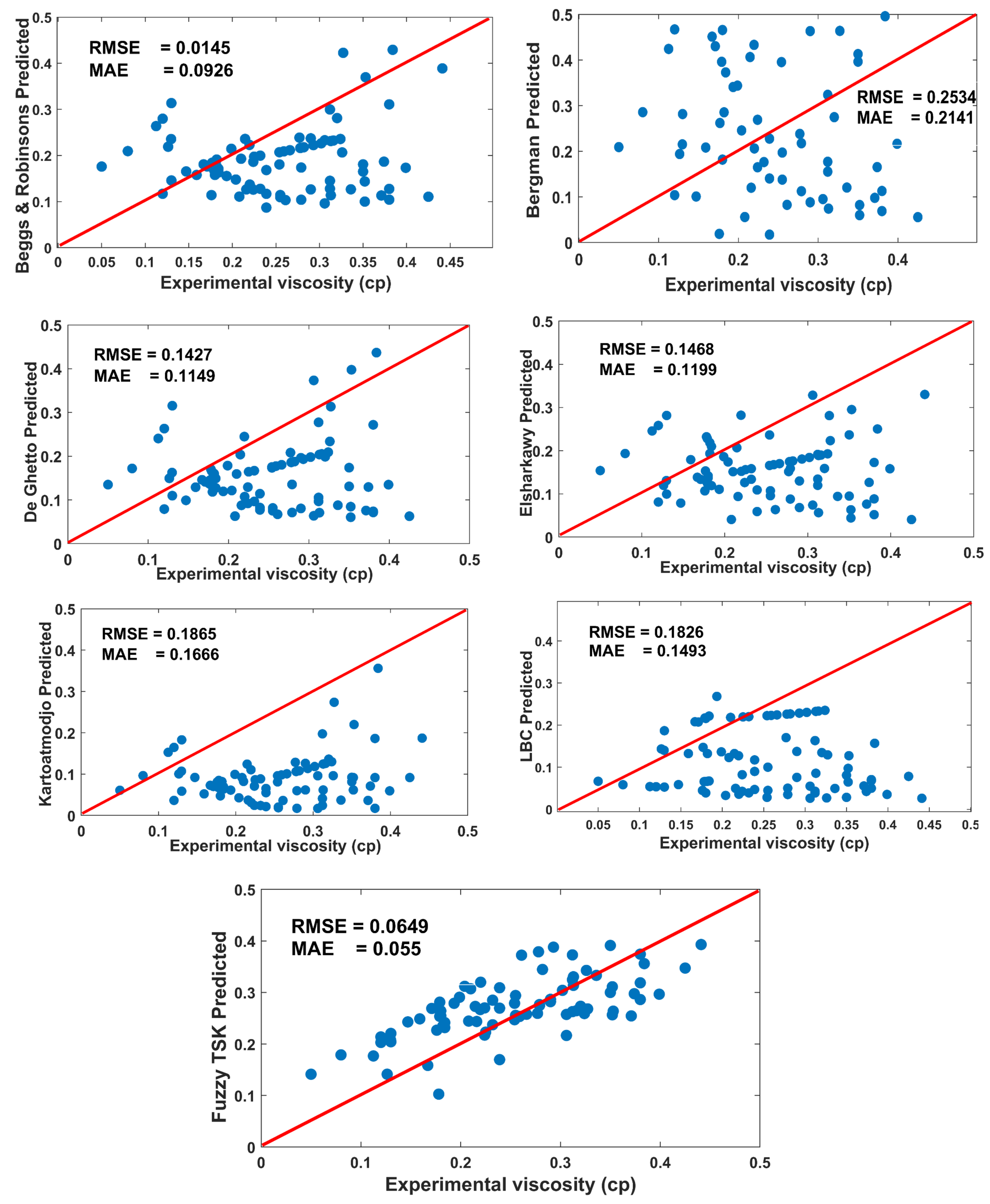


Fig 4. Performance of all utilized methods and Fuzzy method.

- $\boldsymbol{\mu_c}$ performance prediction of the studied correlations are not satisfactory.
- $\boldsymbol{\mu_c}$ is the most difficult and unreliable property to be determined by correlations.
- TSK FIS model was applied for predicting $\boldsymbol{\mu_c}$.
- Fuzzy results yield the closest agreement with the experimental data with lowest RMSE of 0.06493, MAE of 0.0550 and AARD% of 27.91

Conclusion and future work

- Single phase viscosity models cannot predict gas condensate multiphase behaviour below the dew point.
- FIS model performance can be optimized using Genetic Algorithm for future studies.

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