Optimization of Well Spacing for Tight Sandstone Gas Reservoirs --Case study of Eastern Sulige Gas field

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Abstract

Influenced by special geologic condition and stimulation, the production performance of tight fractured gas well is obviously different from that of conventional gas well. During deliverability testing, the hydraulic fractured gas well can never reach steady state with limited test time. It is difficult to calculate reserve and drainage area accurately at early development stage.

Take eastern Sulige gas field for example, by correctly recognizing the percolation characteristics and production performance of hydraulically-fractured tight gas wells, and combined with core analysis, 116 hydraulically fractured tight gas wells in eastern Sulige gas field have been analyzed. A prediction chart of recoverable reserve for estern Sulige gas field is established. With this chart, the ultimately recoverable reserves, drainage sizes, drainage lengths and drainage widths of 116 hydraulically-fractured tight gas wells in eastern Sulige gas field are predicted based on early stage of production data, and finally a reasonable well spacing for this field is suggested. Only utilizing routine production data without employing additional resources, this method is a good predictive guide to launch a development plan of tight gas field.

Introduction

With large recourses in the world, tight gas sands have become hot spots to increase reserve and production for many countries in recent years. For tight reservoir and low natural productivity, tight gas wells should be hydraulically fractured before going into production, and their percolation characteristics and production performance are usually different from those of conventional gas wells, such as:① The dominant flow regime observed in many hydraulically-fractured tight gas wells is linear flow rather than pseudo-radial flow. And this flow regime may continue for several years [1-3]; ②The dynamic reserve and drainage area of hydraulically-fractured tight gas wells vary with production time.

Drainage shape and size of hydraulically-fractured gas wells are significant for planning well spacing/pattern in tight gas reservoirs development. Before we plan to develop a tight gas field, the most important thing we considered is to get the accurate drainage shape and size of the tight gas well in the early production period.

Permeability characteristics of Eastern Sulige Gas field

Eastern Sulige gas field is located in the eastern of Sulige, is characterized as a fine-grained tight gas with clean to dirty sands of found to be interbedded with thin shale streaks at depth ranging from 2700m to 3400m. Permeability ranges from 0.05md and 1.0md, while porosity values lie between 4% and 14%.

Permeability under in-situ stress

For tight core plugs, the impact of overburden pressure on permeability is very strong.**Fig.1** shows the effect of net overburden (NOB) on the measurement of routine air permeability of Eastern Sulige cores. For the core plugs that had values of unstressed permeability of approximately 1.0md, the values of permeability under NOB were approximately an order of magnitude lower, or 0.1md. The lower permeability rocks are the most stress sensitive because the tight core samples have

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smaller pore-throat diameters than the higher-permeability rocks.

31 eastern Sulige cores have been measured under NOB, and 87% of stressed permeability is lower than 0.1md.

Relative permeability of gas and water

Four eastern Sulige cores have been measured to get relative permeability of gas and water. The basic parameters are showed in **table 1**. **Fig.2** shows that the ranges of two phases flow are small, and the relative permeability are lower much than those of high-median permeability cores. Under the irreducible water saturation, gas relative permeability of eastern Sulige is just 30% and 40%.

Table 1 Core parameters for relative permeability measurement

Core NO.	Depth（m）	Routine permeability（md）	Porosity（%）	Irreducible water saturation（%）
X-1	3278.8	0.0899	4.14	42.1
X-2	3171.3	0.1210	5.7	52.3
X-3	3075.6	0.0902	8.17	53.6
X-4	3209.2	0.1370	9.2	44.3

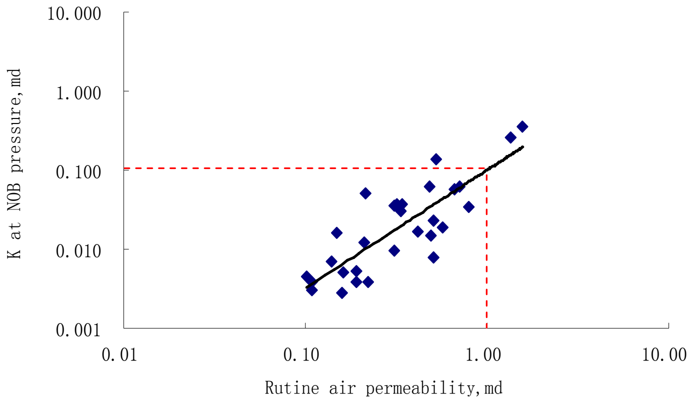

Fig.1-Gas permeability at NOB pressure vs. routine air permeability of eastern Sulige cores

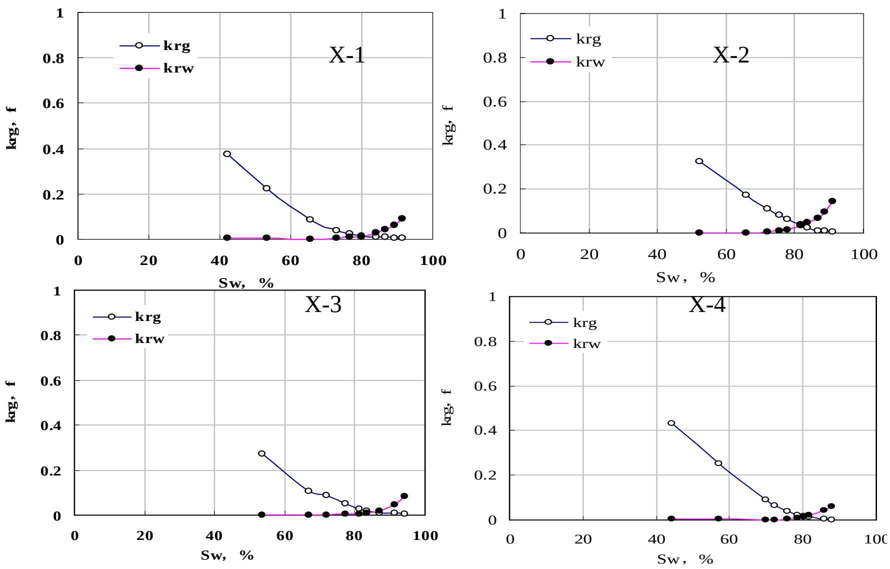

Fig.2-Relative gas and water permeability of eastern Sulige cores

Formation permeability distribution

Permeability in a gas formation within a basin is distributed in log normally. Stephen A. Holditch[2] gave good examples for this(**Fig.3**). The data in **Fig.3** are from four tight gas formations--Cotton Valley formation, Cleveland formation, Wilcox Lobo formation and Travis Peak formation. Theses reservoirs are in different basins, but have very similar log-normal permeability distribution. The median permeability for the four formations ranges from 0.028md to 0.085md. Holditch suggested that the median permeability value is the best measure of central tendency.

Fig.4 shows the formation permeability distribution in eastern Sulige. The data in Fig.4 come from the result of production performance analysis of 116 gas wells in eastern Sulige gas field by using FAST RTA software [4] .From Fig.4, we can see the median permeability of eastern Sulige formation is 0.0475md, which is higher than those of Cotton Valley formation, Cleveland formation and Wilcox Lobo formation. 82% of permeability of eastern Sulige formation is lower than 0.1md, which is consistent with the value of permeability under NOB.

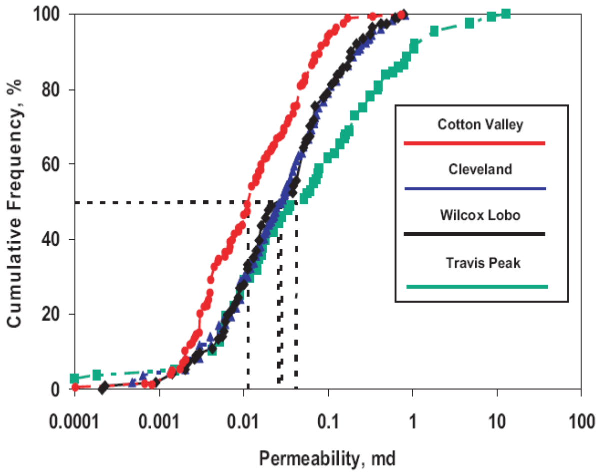

Fig.3- Permeability distribution in four tight sandstone gas formations in Texas using public data (Stephen A. Holditch 2006)

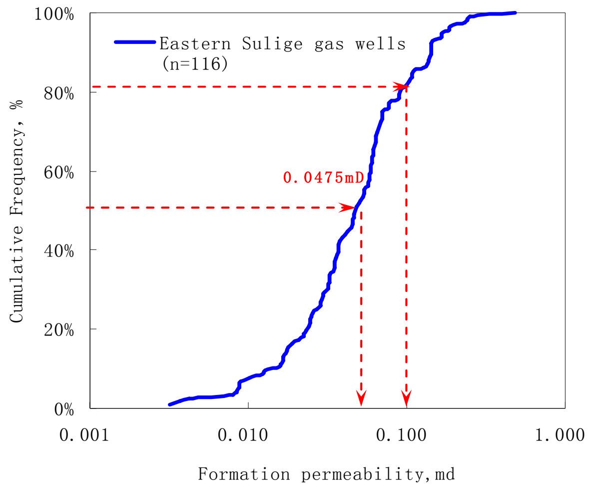

Fig.4-Formation permeability distribution in eastern Sulige

Performance Analysis of Eastern Sulige Gas Wells

For tight formation, gas wells should be hydraulically fractured before going into production, and their production performance are usually different from that of conventional gas wells.Wattenbarger[1] and Nobakht[3] et al. point out that the dominant flow regime observed in many hydraulically-fractured tight gas well is linear flow and this flow regime may continue for several years, and will ultimately become boundary-dominated flow. Wattenbarger[1] introduced the solutions of linear flow into fracture wells in 1998.

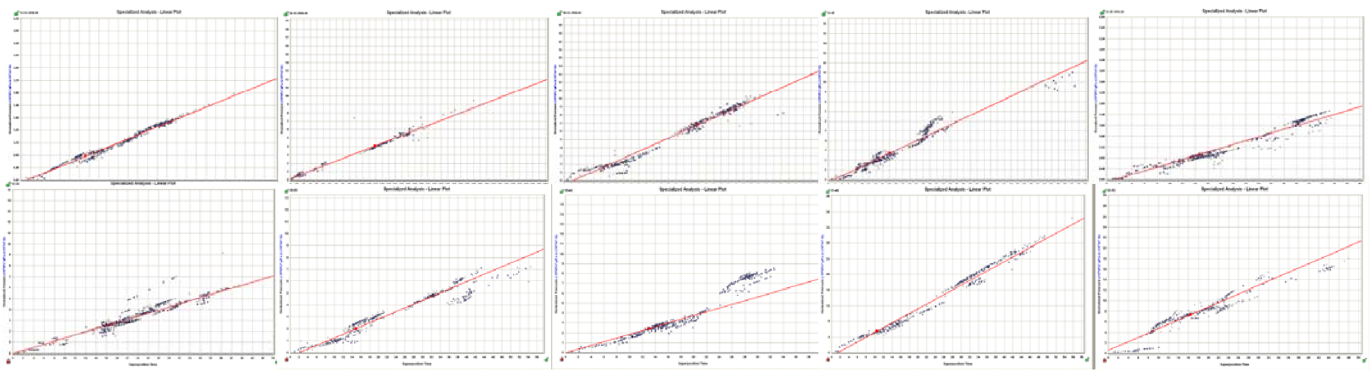

Fig.4- $\frac{p_{pi}-p_{pwf}}{q_n} \sim \sum_{j=1}^{n}\frac{q_j-q_{j-1}}{q_n}\sqrt{t-t_{j-1}}$ plot for 10 wells in eastern Sulige formation

Production performance of 116 Eastern Sulige wells has been analyzed by FAST RTA. **Fig.4** shows a plot of inverse gas rate versus square root superposition time for some 10 wells in the Eastern Sulige formation. The result shows that the dominant flow regime of most of Eastern Sulige wells is linear flow, and none of the wells show pseudo-radial flow theoretically. So we can use Wattenbarger's type curve to make analysis to get drainage area and dynamic reserve of individual wells.

For tight gas wells, since the period of transient flow is very long, the dynamic reserves and drainage area vary greatly with production time [5]. We establish prediction chart of dynamic reserves for Eastern Sulige wells with considering the properties of Eastern Sulige formation, show as **Fig.5** and **Fig.6**. With this chart, by using early stage of production data, the dynamic reserves and drainage area of gas wells can be predicted effectively with time.

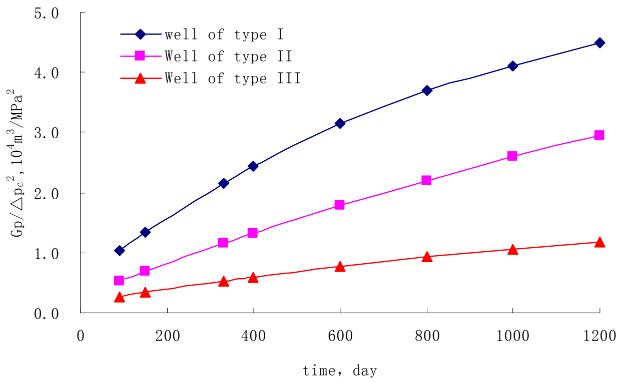

Fig.5-Relationship $G_p / \Delta p_c^2 \sim t$ of three kind of typical wells

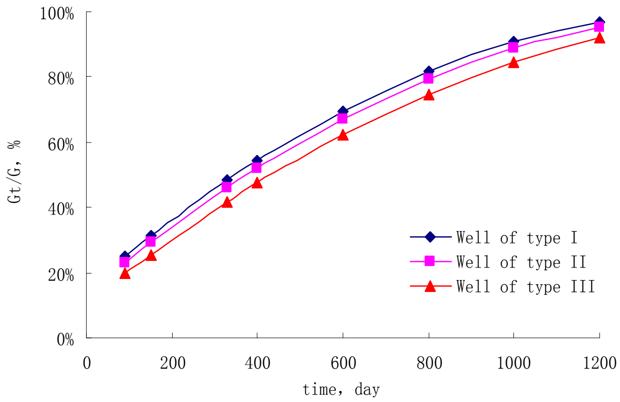

Fig.6- Dynamic reserves vs. time of typical gas wells

Combined with Wattenbarger's type curve analysis and prediction chart of dynamic reserves, the ultimately recoverable reserves, drainage sizes, drainage lengths and drainage widths of 116 hydraulically-fractured tight gas wells in Eastern Sulige are predicted, show as **Fig.7**~ **Fig.10. Fig.7** is the plot of dynamic reserves distribution of Eastern Sulige wells. Average ultimate-reserve of individual wells is $19.43\times10^6 m^3$, and median ultimate-reserve of individual wells is only $16.65\times10^6 m^3$. **Fig.8** is the plot of drainage size distribution of Eastern Sulige wells. Average drainage area of individual wells is $0.179 km^2$, and median drainage area of individual wells is only $0.148 km^2$. These data indicate that it is not easy to develop Eastern Sulige high efficiently.

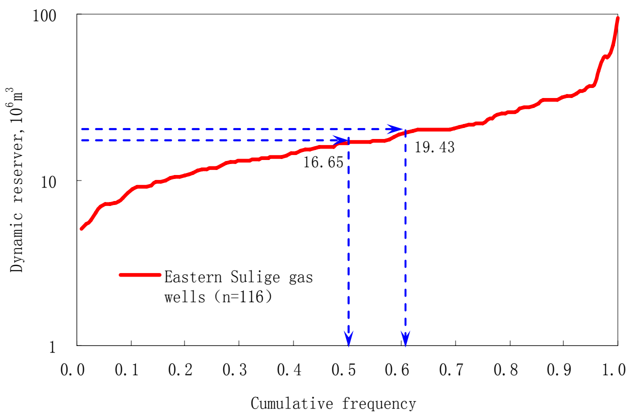

Fig.7- Dynamic reserves distribution of Eastern Sulige wells

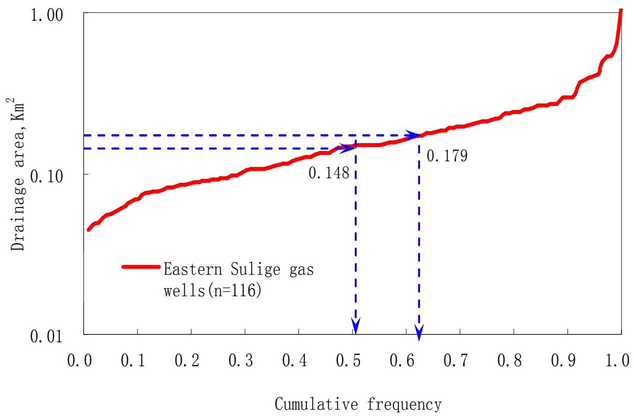

Fig.8- Drainage size distribution of Eastern Sulige wells

Fig.9 is the plots of drainage length and width distribution of eastern Sulige wells. Median drainage-length of individual wells is 553m, and median drainage-width of individual wells is 257m. **Fig.10** is the plot of ratio of drainage length and width distribution of eastern Sulige wells. Median ratio of drainage length and width of individual wells in Eastern Sulige is 2, and the average ratio is 2.45.Based on this data, in order to get high level of reserves producing and low probability of well interference, we suggest that reasonable well spacing for eastern Sulige gas field is 350m-450m in width, and 800m-1000m in length, show as Fig11.

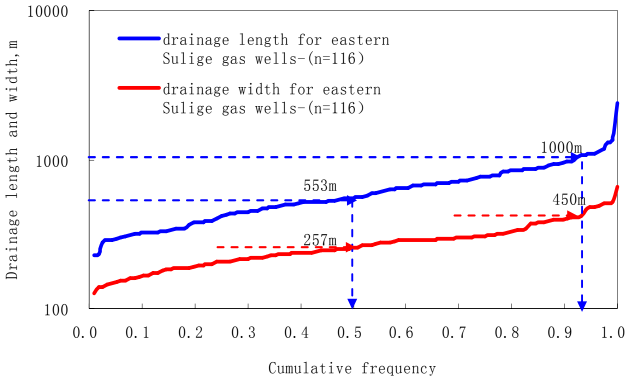

Fig.9- Drainage length and width distribution of eastern Sulige wells

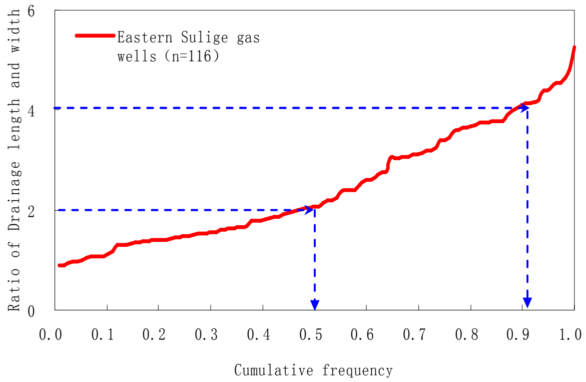

Fig.10-Ratio of drainage length and width distribution of eastern Sulige wells

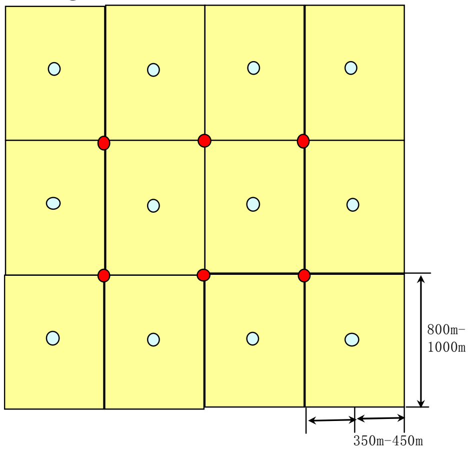

Fig.11-Well spacing for Eastern Sulige

Conclusions

(1)Eastern Sulige gas field is a typical tight sands gas, more than 80 percents of formation permeability is lower than 0.1mD;

(2)The dominant flow regime observed in eastern Sulige tight gas wells is linear flow. The drainage shapes of eastern Sulige tight gas wells are rectangles rather than circulars;

(3)Combined with Wattenbarger's type curve analysis and prediction chart of dynamic reserves, the ultimately recoverable reserves, drainage sizes, drainage lengths and drainage widths of 116 hydraulically-fractured wells in eastern Sulige are predicted. It is suggest that reasonable well spacing for eastern Sulige gas field is 350m-450m in width, and 800m-1000m in length.

Nomenclature

G_p = cumulative gas production at the time of t, $10^6 m^3$;

G_t = dynamic reserve at the time of t, $10^6 m^3$;

Δp_c^2 = casing pressure drop， MPa^2;

T= effective production time (except shut-in time),day;

References

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