

# Field Case Study Using Modified Type Curve Solutions for Production Decline Analysis of Multistage Hydraulically Fractured Horizontal Wells for Unconventional Resource Development

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## Summary

Production decline analysis for multistage hydraulically fractured horizontal wells (MHFHW) plays a key role in developing unconventional resources, such as Bakken tight oil, Duvernay and Montney unconventional resources, Eagle ford shale oil and Barnett shale gas, mainly due to the huge cost and risk associated with successful drilling, completing and operation of MHFHW. The unconventional resource exploitation under very complicated reservoir environment requires solid technical capacity to understand, analyze and characterize well performance accordingly. Understanding production decline behavior of MHFHW with the consideration of completion parameters and reservoir system information is necessary and challenging. This presentation shows our recent research outcomes in modeling and analyzing production decline of MHFHW and their application in field case study. The influence of both reservoir properties and reservoir-well-fracture geometry information on the transient rate response of MHFHW are integratively organized in a standardized form to facilitate systematic field production data analysis. The framework implemented is applicable for other MHFHW cases as well. Field data from Bakken tight oil formation, Duvernay and Montney unconventional resources, and Eagle ford shale oil were collected and analyzed to enhance our understanding of the MHFHW-reservoir systems in terms of their characterization and dynamic transient rate responses, thus, to support resource development.

## Theory / Method / Workflow

The semi-analytical modeling methodology was applied to generate highly accurate solutions for MHFHW-reservoir systems. Then the solutions were reorganized by applying the modified dimensionless rate term of modified dimensionless time term. Unique sets of modified dimensionless typer curves were generated to support MHFHW practice in unconventional and conventional resources development. This research is based on the work of Zhao and Thompson (2002) and Zhao (2012) by applying semi-analytical modeling strategy. The concept of material balance time proposed by Palacio, J.C. and Blasingame (1993) was applied and further modified in the work of Zhao et al. (2016) which further improved the work by Nobakht et al. (2011) for single vertical fracture modeling for unconventional resource development.

The general idealized MHFHW-reservoir system is defined as shown in **Fig. 1**. MHFHW assumes uniformly distributed fracture spacing along the horizontal trajectory, individual vertical fracture penetrating formation fully with same fracture half-length, and homogeneous reservoir properties under isothermal condition are presented in the model. The reference reservoir is specified as  $Y_e = X_e$ ,  $L_w/X_e = 1/7$  and  $C_T = 1$  for homogeneous reservoir condition (Zhao et al., 2016). This arrangement allows potential to investigate 7 x 7 reservoir gridding to deal with simplified reservoir

heterogeneities. The main parameters under investigation presently are  $2L_f/L_w$  ratio and  $N_{stage}$ . This model is constructed to serve as the theoretical base for future complicated field case study.

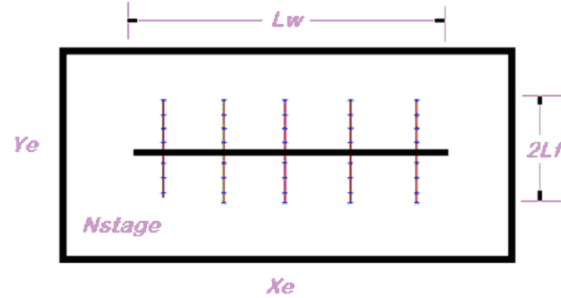


Fig. 1. A brief schematic of the MHFHW-reservoir system under study, after Zhao et al. (2016)

## Results, Discussions, Observations

The semi-analytical modeling outcomes for the general MHFHW-reservoir model described above are presented below. For further details regarding the modeling methodology, readers are referring to the work of Zhao et al. (2016).

**Fig. 2** shows the fluid flow rate flux along each fracture, in this case, 9 vertical fractures were assumed in total, with 9 subsegments specified for each fracture. This figure reveals how the flow regimes, further details are presented in **Fig. 3**, appear with respect to time graphically. Fig. 3 exemplifies the typical flow regimes of MHFHW under the specified conditions. One may realize that the regions from I to IV are for the flow regimes of each individual fracture, these regions exist before the occurrence of interference among fractures, under the assumed condition of uniformly distributed fractures along the horizontal wellbore trajectory.

Applying the modified dimensionless terms defined in the *Appendix B* of Zhao et al. (2016), the following notations are defined:

$$q_{DM} = q_D \cdot \frac{Scaler}{N_{stage}}, \quad (1)$$

$$t_{DM} = \frac{t_{MBD\_Lf}}{Scaler^2}, \quad (2)$$

where, the  $q_{DM}$  and  $t_{DM}$  are the modified dimensionless rate and time terms, respectively. The scaler is a MHFHW-reservoir system defined parameter to rescale the well response, thus the name. For a two-dimensional simplification of the system, its definition is:

$$Scaler = \frac{X_e \cdot Y_e}{L_f^2} \cdot \frac{1}{N_{stage}}. \quad (3)$$

The definition of  $t_{MBD\_Lf}$  is based on the corresponding  $t_{MBD}(t_D)$  of the MHFHW-reservoir system as shown in Eq. (4), where the  $q_D(t_D) \sim t_D$  solution under specified unit-pressure-change condition was originally generated for such system. The  $N_{stage}$  term is the total number of the evenly distributed fractures.

$$t_{MBD\_Lf} = \frac{t_{MBD}(t_D)}{L_{fD}^2}, \quad (4)$$

where, the dimensionless material balance time proposed by Palacio, J.C. and Blasingame (1993),  $t_{MBD}$ , is defined as

$$t_{MBD}(t_D) = \frac{\int_0^{t_D} q(\tau_D) d\tau_D}{q_D(t_D)} = \frac{Q_D(t_D)}{q_D(t_D)}, \quad (5)$$

The  $q_D(t_D) \sim t_D$  terms are defined accordingly as usual:

$$q_D(t_D) = \frac{141.2q(t)\mu}{kh\Delta p_u}, \quad (6)$$

$$t_D = \frac{0.006328k}{\phi\mu c_t l^2} t, \quad (7)$$

where,  $k$  is permeability,  $h$  is formation thickness,  $\mu$  is fluid viscosity,  $\phi$  is porosity,  $c_t$  is total compressibility. The characteristic length,  $l$ , is applied to define spatial terms, such that

$$L_{fD} = \frac{L_{fD}}{l}, x_D = \frac{x}{l}, \text{ and } y_D = \frac{y}{l}. \quad (8)$$

Using a single vertical fracture's response in the correspondingly same reservoir as a comparing base.  $L_{f_{qDM}}$  is defined as the dimensionless modified half quasi-fracture length and  $f_{qDM}$  the modified quasi-fracture length.

$$f_{qDM} = 2L_{f_{qDM}} = q_{DM}\sqrt{\pi^3 t_{DM}}. \quad (9)$$

Applying the modified dimensionless term for  $f_{qDM}$  versus  $t_{DM}$ , the unique sets of type curves under different  $2L_f/L_w$  ratios (**Fig. 4**) and different  $N_{stage}$  (**Fig. 5**) are presented. In another word, Figures 4 and 5 use the dynamic flow regimes of a single vertical fracture well under the same conditions as the dynamic reference states to generate the modified type curve solutions for the modeling and analysis of MHFHW-reservoir systems.

Applying the modified dimensionless term for  $q_{DM}$  versus  $t_{DM}$ , the unique sets of modified dimensionless type curves under different  $2L_f/L_w$  ratios (**Fig. 6**) and different  $N_{stage}$  (**Fig. 7**) are presented. The modified dimensionless terms of  $q_{DM}$  and  $t_{DM}$  help organize the dimensionless type curves in a unique manner that all the early- and late-time responses fall on their corresponding early and late time stem accordingly as shown. These sets of modified dimensionless type curves can greatly assist modeling, analyzing and characterizing MHFHW-reservoir systems.

By setting up a model with  $X_e/Y_e=3/1$  and  $L_w/X_e=1400/1600$  to simulate a scenario that is more like general field operation by deploying three MHFHWs within one section area size of a reservoir. **Fig. 8** combines  $q_{DM}$  and  $f_{qDM}$  vs.  $t_{DM}$  type curves under different  $2L_f/L_w$  ratios, with  $N_{stage}=16$ , while **Fig. 9** investigated the influence of  $N_{stage}$  under the conditions of  $2L_f/L_w=100/1400$ . It is realized that a combination of  $q_{DM}$  and  $f_{qDM}$  vs.  $t_{DM}$  type curves offer advantages for field production data analysis, as experienced in several field case studies.

**Fig. 10** presents a set of  $q_D$  vs.  $Q_D$  type curves under the condition shown on the plot. This figure helps identify the relationship between  $q_D$  and  $Q_D$  clearly.

The modified dimensionless type curve solutions presented basically provide clear characterization of the MHFHW-reservoir systems under given conditions. They can be applied

to analyze field production data by applying superposition principle, especially when reliable well bottomhole pressure data are available, or through de-convolution analysis to identify the transient rate response under unit pressure change conditions to assist characterizing MHFHW-reservoir systems.

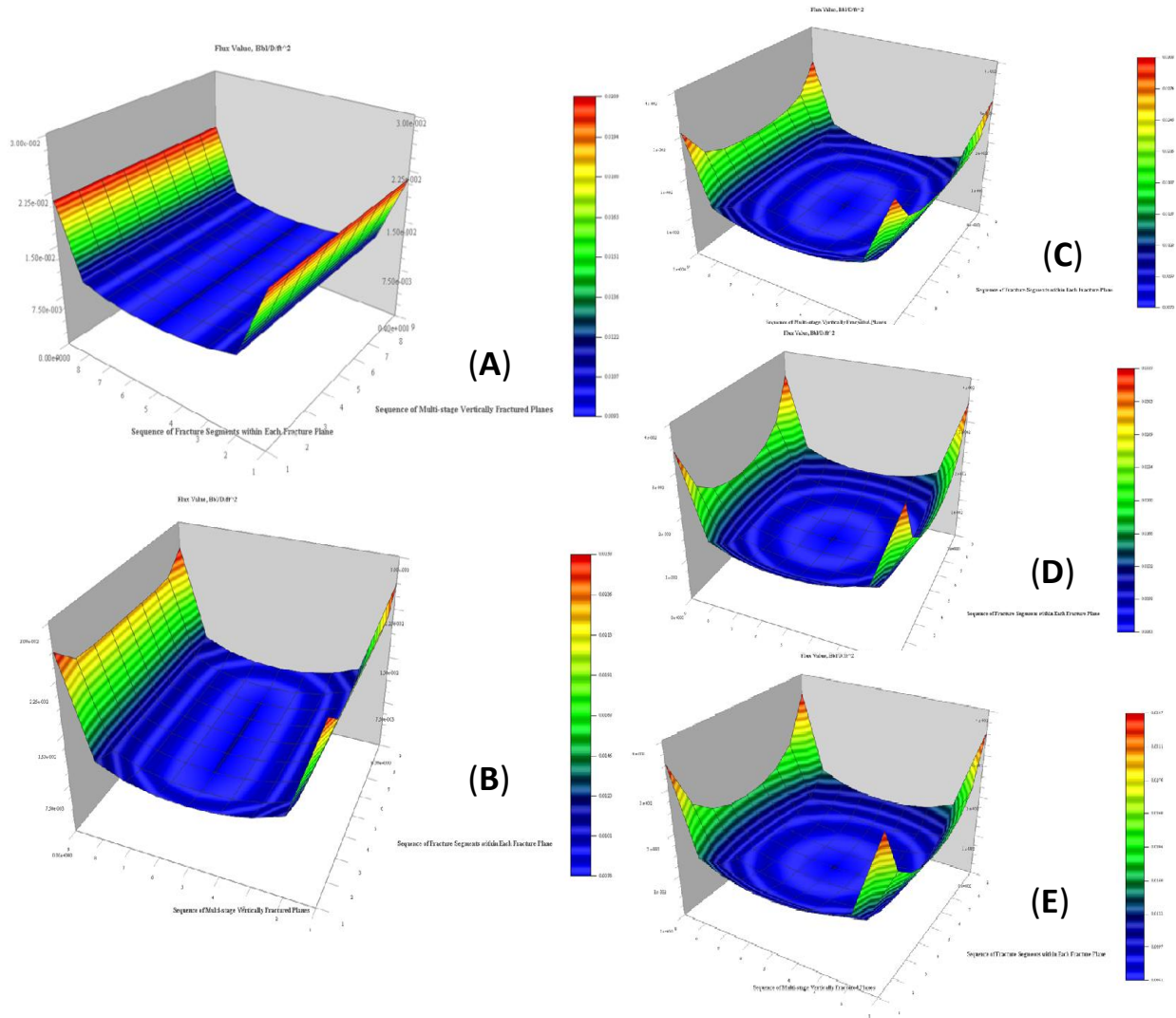


Fig. 2. Idealized MHFHW-reservoir system, with the general flow regimes graphically reflective of flow flux along nine fractures, Zhao and Thompson (2012), permission of SPE

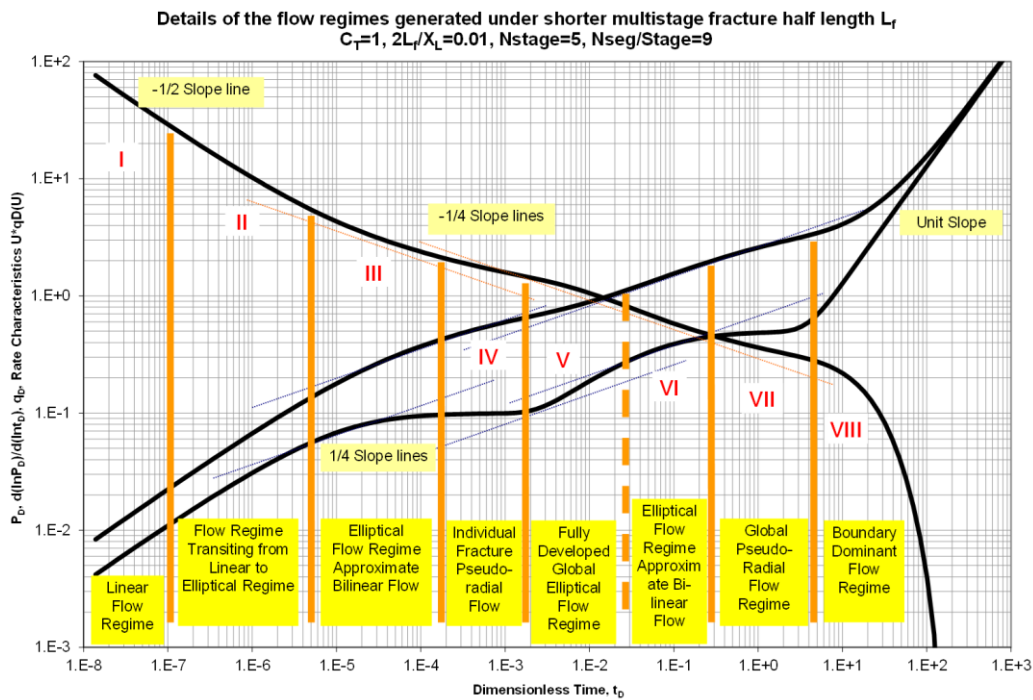


Fig. 3. Typical flow regimes of MHFW under specified conditions,  $N_{stage}=5, 2L_f/L_w=0.01$  for reference

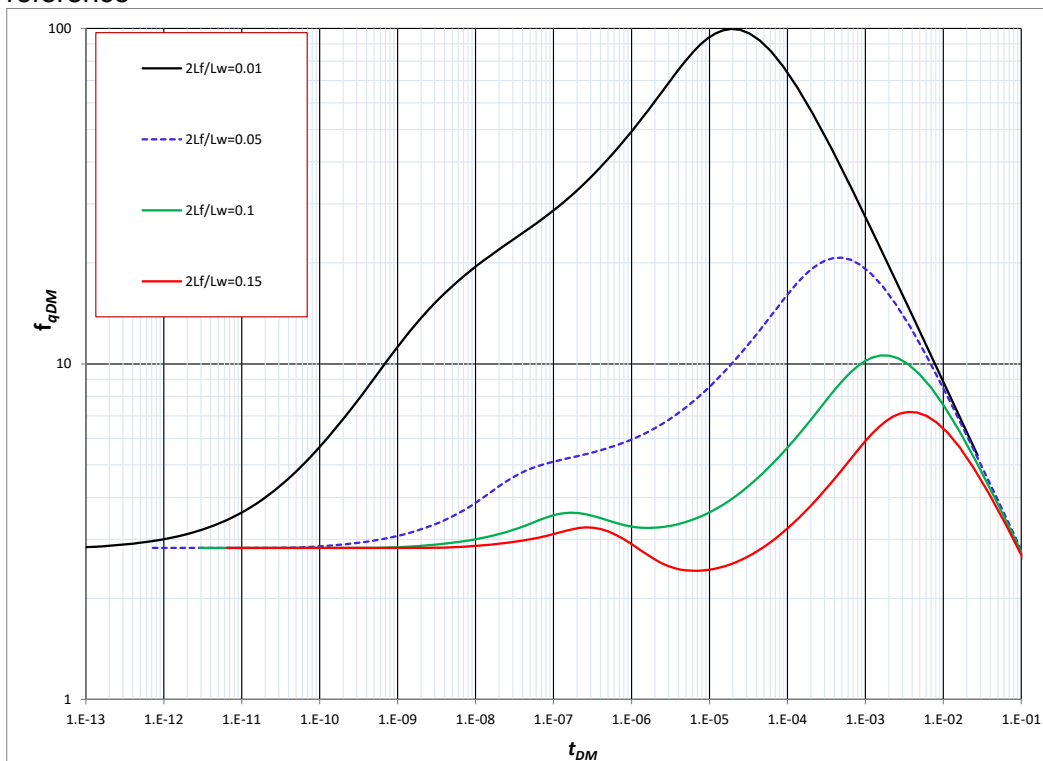


Fig. 4.  $f_{qDM}$  vs.  $t_{DM}$  under different  $2L_f/L_w$  ratios for reference reservoir with  $N_{stage}=10$ , modified after Zhao et al. (2016)

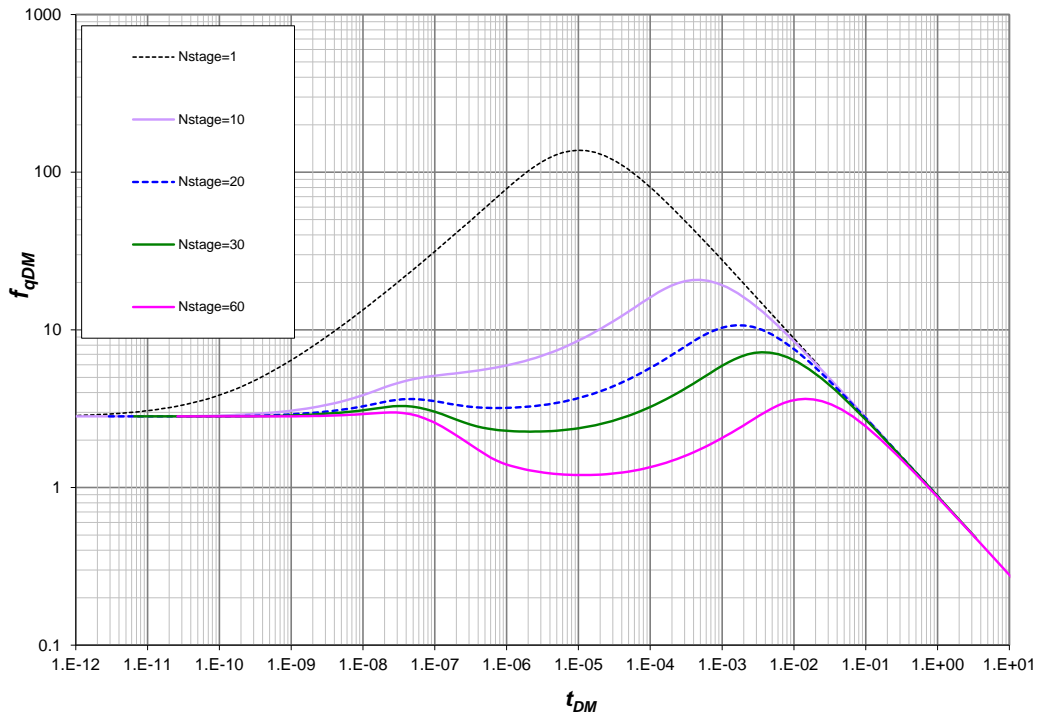


Fig. 5.  $f_{qDM}$  versus  $t_{DM}$  under different  $N_{stage}$  for reference reservoir with  $2L_f/L_w=0.05$ , modified after Zhao et al. (2016)

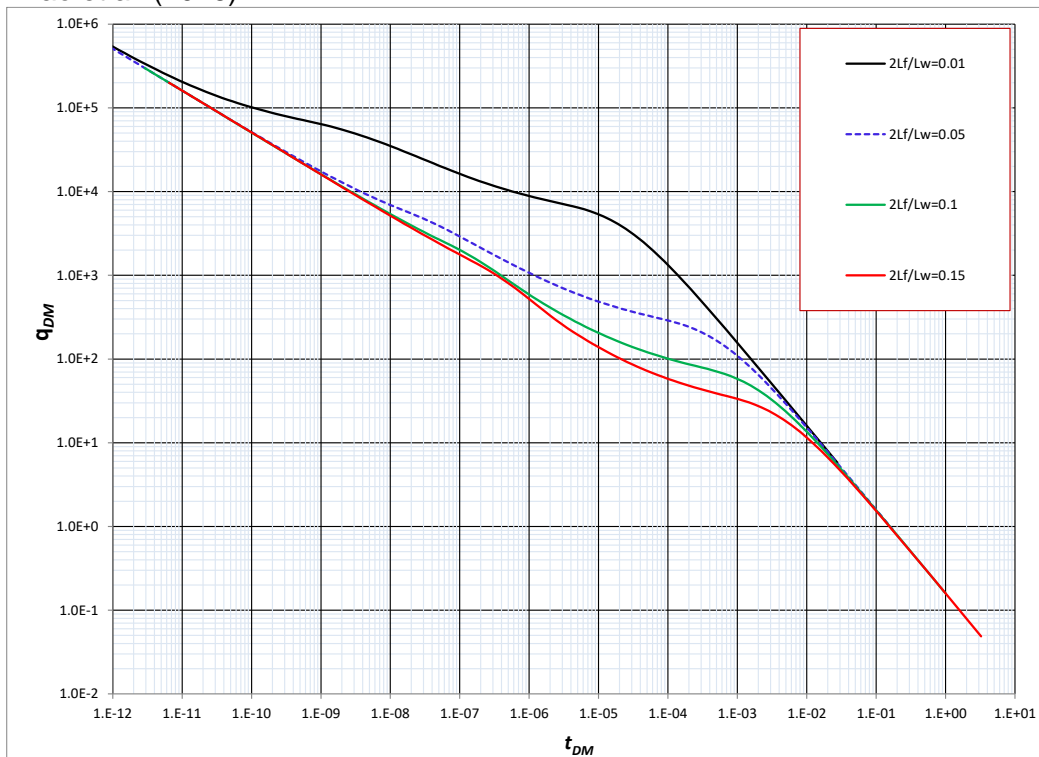


Fig. 6.  $q_{DM}$  vs.  $t_{DM}$  under different  $2L_f/L_w$  ratios with  $N_{stage}=10$ , modified after Zhao et al. (2016)

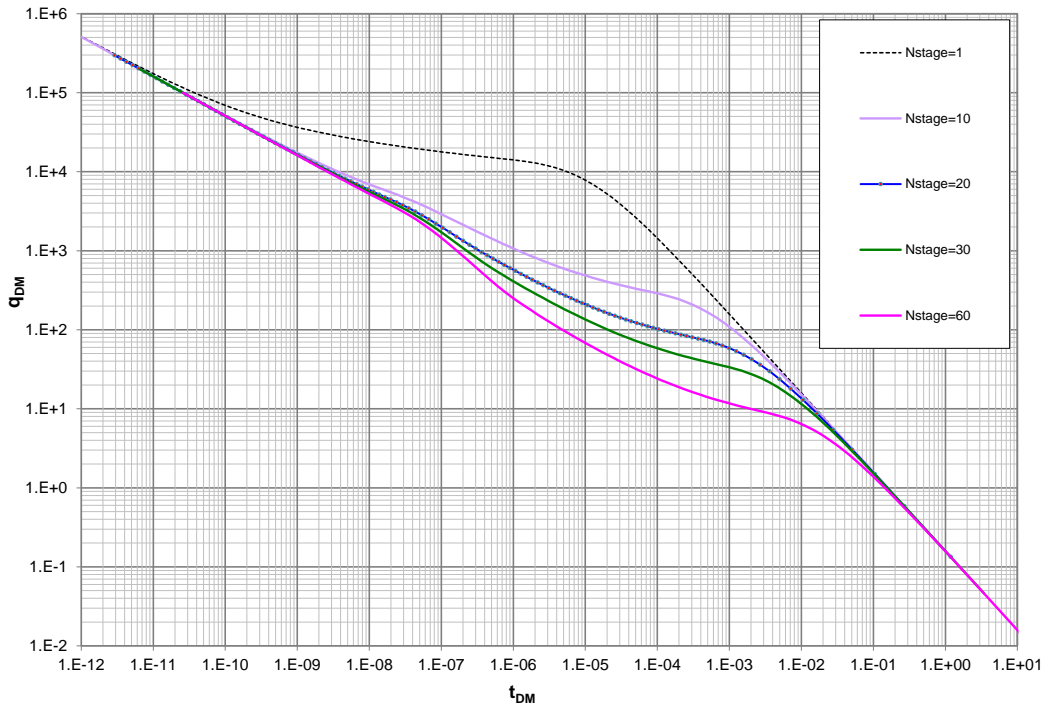


Fig. 7.  $q_{DM}$  versus  $t_{DM}$  under different  $N_{stage}$  with  $2L_f/L_w = 0.05/7$ , modified after Zhao et al. (2016)

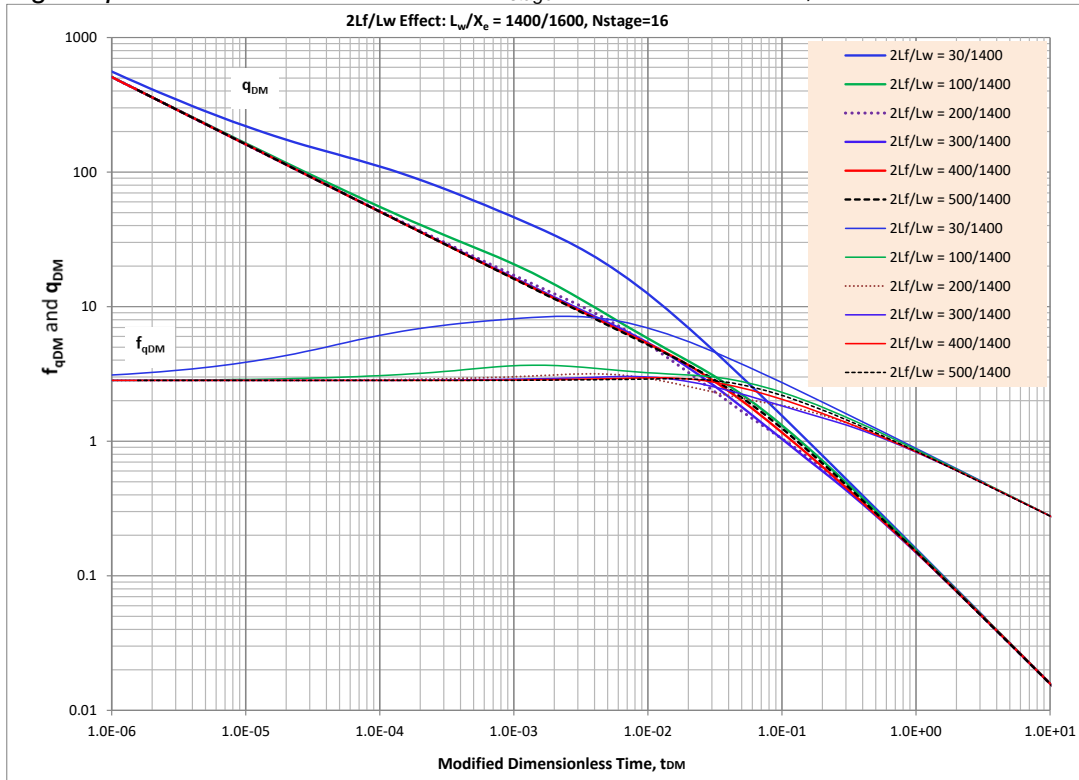


Fig. 8.  $q_{DM}$  and  $f_{qDM}$  vs.  $t_{DM}$  under different  $2L_f/L_w$  ratios, with  $N_{stage}=16$ ,  $L_w/X_e=1400/1600$

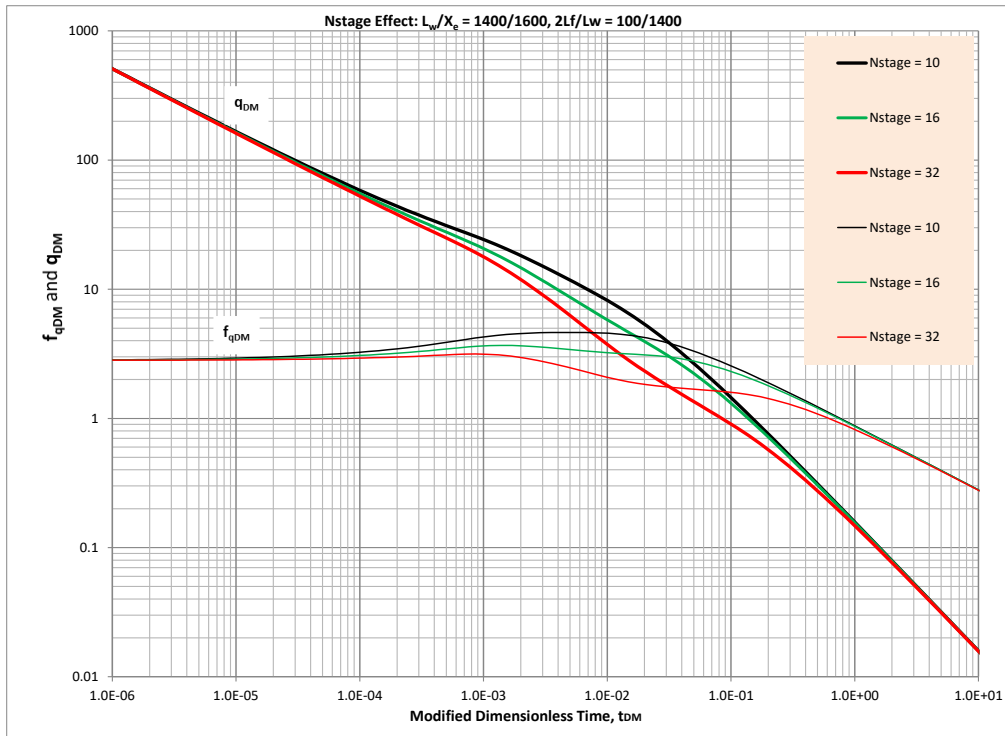


Fig. 9.  $q_{DM}$  and  $f_{qDM}$  vs.  $t_{DM}$  under different  $N_{stage}$ , with  $L_w/X_e=1400/1600$ ,  $2L_f/L_w=100/1400$

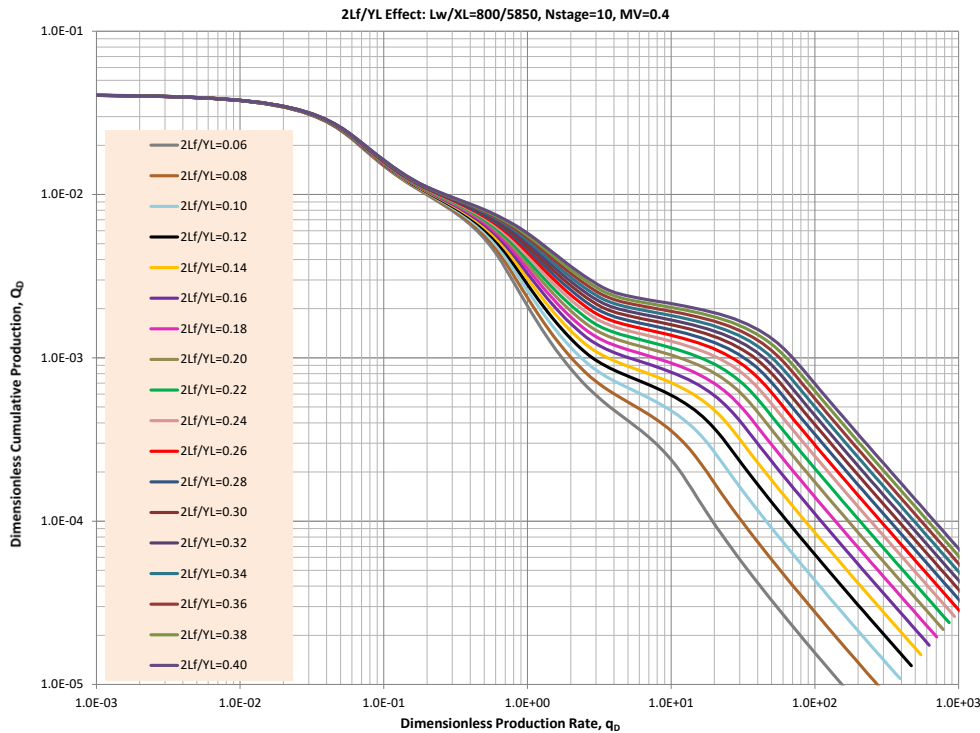


Fig. 10. A set of  $q_D$  vs.  $Q_D$  type curves under the condition shown,  $MV=0.4$  is MHFW off the reservoir center by  $0.4X_e$ ,  $X_L=X_e$ ,  $Y_L=Y_e$

## Conclusions

1. The modified dimensionless terms and type curves presented can help reach reliable reservoir characterization, MHFHW performance modeling, analysis, and future prediction under the MHFHW-reservoir system conditions specified.
2. It is realized that a combination of  $q_{DM}$  and  $f_{qDM}$  vs.  $t_{DM}$  type curves offers advantages for field production data analysis.
3. The performance of MHFHWs under various conditions globally becomes systematically comparable by applying the modified dimensionless type curves. Therefore, the uncertainty for tight formation multistage fracturing design and operation can be largely reduced.

## Novel/Additive Information

Applying the modified dimensionless terms of  $q_{DM}$  and  $t_{DM}$ , further work to explore the influence of complicated hydraulic fracture system around wellbore, finite fracture conductivity, natural fracture network inside reservoir, matrix heterogeneity of reservoir, and reservoirs consisting of multiple layers will be conducted.

## Acknowledgements

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