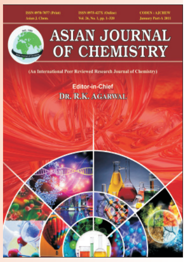
Asian Journal of Chemistry;   Vol. 26, No. 17 (2014), 5567-5570

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2014.18156



Oil Well Breakdown Pressure in Blasting Force Loading Condition†

FEI-PENG WU[1,*], DE-CHUN CHEN[1], CHUN-SHENG PU[1], XUE-MEI WEI[2] and MIN LIU[1]

[1]College of Petroleum Engineering in China University of Petroleum, Shandong, Qingdao 266555, P.R. China
[2]Geology Science Research Institute of Shengli Oilfield, Dongying 257061, P.R. China

*Corresponding author: E-mail: upcwfp@163.com

AJC-15745

Based on the problem of the quantitative description of blasting well breakdown pressure, 19 experiments on rock cracking of 3 tensile strengths and 5 loading rates using the rock dynamic cracking simulation device were conducted. The experiments verify that the device can crack the small simulation hole immediately as well as offer loading rate below 153.17 MPa/ms, which can simulate the real blasting fracturing condition completely. Based on the regression analysis of experimental data, relationship between the difference value of dynamic/static breakdown pressure and the loading rate tends to be logarithm. The regression model presents a calculation error of 0.95 %. The results can help to ascertain minimum peak pressure in the design of detonation pressure as well as enhance the production of universal application and the success ratio.

Keywords: Blasting pressure, Loading rate, Breakdown pressure, Experimental study, Computation module.

INTRODUCTION

High energy gas fracturing (HEGF) was originated and developed in mid-1956 and has been paid more and more attention recently, along with the increasing exploitation of the deep-seated, low permeability and tight hydrocarbon reservoirs[1,2].

Recently more and more attention is paid to the high energy gas fracturing and composite measures, along with the increasing exploitation of the deep-seated, low permeability and tight hydrocarbon reservoirs[1,2]. The quantitative calculation of fracturing pressure under the high loading rate is one of the key elements to restrict the complete and overall popularization[3-5]. Recently, the problems about high dynamic loading rock strengths are mainly solved by Hopkingson bar (SHPB) experiments to induce the rock tensile strengths changing principle under the dynamic loading condition and then to get the breakdown pressure under the dynamic loading condition by the computation of the relative pressure with the static loading[6,8]. High energy gas fracturing is a product-increasing measure based on rock racking at a momentary and high loading rate, so its rock racking principle is extremely complex. Consequently, the SHPB experiments method cannot obtain the accurate rock breakdown peak pressure, which induce the absurdity of the blasting amounts design and the operation's failure. Using the "rock dynamic cracking simulation device", this research conducts high dynamic loading rock racking experiments on small simulation wellbores directly. The experiments can help design wellbores simulation of different rock strengths. Moreover, they can quantitatively design the pressure loading rate and peak pressure of blasting dynamic loading as well as simulate distinct formational pressure. Through the practical condition simulation of the HEGF in oil wells and analysis, the experiments can acquire the quantitative relationship between oil wells' breakdown pressure and the loading rate.In this case, the research will play a significant role in guiding practical designaccurately and economically.

Experimental device and principle: The rock dynamic cracking simulation device consists of blast formation facility, core holding unit, pumping pressure system, controlling and measuring system and the allied accessory equipment[9]. The device uses an object to bump the inner free piston in core holding unit under free falling condition. During the process, the bumping will compress the fluids in the simulation wellbore and then create dynamic pressure on the wall of core simulation wellbore, thus the device can simulate the effects of strong loading condition such as blasting fracturing in wells on oil layers nearby.

Design of experimental core: The cores used in this experiment are the simulation cores made of the mixture of cements

---

†Presented at 2014 Global Conference on Polymer and Composite Materials (PCM2014) held on 27-29 May 2014, Ningbo, P.R. China

and sands. In this experiment, the cements include three types, *i.e.*, type 32.5, type 42.5 and type 52.5; mean while, the diameter of the applied sands is in the interval of [0.75, 0.80] mm. After mixing the cement and chosen sand at the ratio of 1:1, the cores can be made. After 7 days' solidifying, the cores can be tailored into samples (6 mm in inner diameter 80 mm in outer diameter, 45 mm in height). Rock strengths test reveals that the tensile strengths of the three types of cores are separately 2.38, 4.59 and 7.34 MPa.

Computation analysis of blasting peak pressure and design on experimental plan: In the experiment, one object falls freely from certain height. The motion starts at the beginning of the bumping and ends at the final movement together with inner free piston. This motion pattern is assumed as the simple harmonic motion (SHM), *i.e.*, simplifying the liquid compressing process to the motion of a spring. Without considering the fiction and bounce effects, based on momentum and energy conservation law and the relevant experimental research[3], the computation models of peak pressure and average loading rate are obtained as following[10]

$$P_{max} - P_0 = 0.9254\sqrt{\frac{2mgH}{CV_0}} \qquad \text{(I)}$$

$$\frac{\Delta P}{T} = \frac{P_{max} - P_0}{T} = \frac{3.8684A_P}{\pi CV_0}\sqrt{2gH} \qquad \text{(II)}$$

where P_{max} stands for peak pressure (Pa); m stands for weight of the free falling object (Kg); H stands for the height of the free falling object (m); g stands for acceleration of gravity, m/s^2; C stands for the compressibility coefficient[5], Pa^{-1}; V_0 stands for the simulation wellbore volume, m^3; A_p stands for the area of inner motion plunger, m^2.

Based on formula (I), formula (II) and the experimental condition limit, an array of five groups of objects' height and weight is designed in the experiment. In order to simulate the practical loading process of the practical HEGF, all the objects' peak pressure are around 180MPa and their loading rates are 76.4, 85.4, 101.0, 120.8 and 142.9 MPa/ms separately.

EXPERIMENTAL

Static loading breakdown pressure analysis of simulation cores: The core in experiment shapes as a thick wall cylinder with inner diameter am, outer diameter bm. The inner pressure of the wellbore is p_a MPa and the outer pressure p_b MPa (Fig. 1).

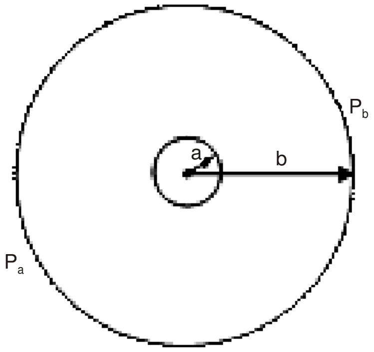


Fig. 1. Sketch map of the core cross-sectional

Based on elasticity mechanics, the calculation formulas of thick wall cylinder (assuming positive tensile stress) are

$$\begin{cases} \sigma_r = \dfrac{a^2}{b^2 - a^2}\left(1 - \dfrac{b^2}{r^2}\right)p_a - \dfrac{b^2}{b^2 - a^2}\left(1 - \dfrac{a^2}{r^2}\right)p_b \\ \sigma_\theta = \dfrac{a^2}{b^2 - a^2}\left(1 + \dfrac{b^2}{r^2}\right)p_a - \dfrac{b^2}{b^2 - a^2}\left(1 + \dfrac{a^2}{r^2}\right)p_b \\ \tau_{r\theta} = 0 \end{cases} \qquad \text{(III)}$$

When the circuit stress on cylinder inner wall $\sigma_\theta\big|_{r=a}$ reaches the core's tensile strength σ_t^h the core will develop brittle break. At the same time, the present pressure on the inner wall P_a is the core's breakdown pressure p_f which can be obtained by the following function,

$$p_f = \left(\sigma_t^h + \frac{2b^2}{b^2 - a^2}p_b\right)\frac{b^2 - a^2}{b^2 + a^2} \qquad \text{(IV)}$$

where σ_r stands for rock's radial stress, MPa; σ_θ stands for rock's circuit stress, MPa; $\tau_{r\theta}$ stands for rock's shearing stress, MPa; p_f stands for the break down pressure of the core in experiment, MPa.

Analysis of blast loading curve: The curve of rock cracking pressure loading and time (Fig. 2) presents 5 distinct changing segments.

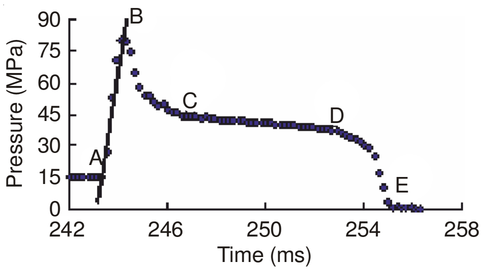


Fig. 2. Pressure-time curve

AB segment is the loading period. During this period, the core is shocked at point A and in 1.14 ms it reaches the peak pressure 80.98 MPa (point B); however the calculation peak pressure is 177.1 MPa, so it illustrates that the core is cracked at point B. This means that 80.98 MPa is the core's breakdown pressure. The core after experiment is shown in Fig. 3.

Fig. 3. Cracked core

BC segment is pressure reliving period. After cracking, though the object moves downward continually, the core axial canal pressure pierces with the confining pressure, for the core has been cracked out of seam. Therefore, the pressure declines to the same value as the confining pressure, which shows how the BC segment comes into being. CD segment is continuing loading period. During this period, the core axial canal pressure at the time has dropped to the value of the confining pressure because of the existence of the seam. But the free falling object is still moving downwards, so the core axial canal is in the closed compressing condition and its pressure will maintain. The segment after point D is core axial canal pressure relieving period. During this period, the free falling object has come to the end and then it begins to bounce upwards, so the core axial canal space enlarges at a changing acceleration. Then the pressure will discharge quickly until the free falling object breaks away with the piston when the pressure is at the lowest. Analysis accounts that the AB segment is linear loading period, so proceeding linear regression of AB segment's pressure and time' relationship can lead to a formula obtained as

$$P(t) = 74.659 \times t - 18152 \qquad \text{(V)}$$

Thus the real loading rate in the experiment is

$$\gamma = \frac{dp(t)}{dt} = 74.659 \text{ MPa/ms} \qquad \text{(VI)}$$

RESULTS AND DISCUSSION

Up to 19 experiments in this research were conducted successfully. The formula (IV) is used to calculate core's breakdown pressure under static loading while pressure-time real measured curve and formula (VI) are used to calculate the core's accelerating rate caused by strong dynamic loading. All of the measured and calculate data is shown in Table-1.

TABLE-1
EXPERIMENTAL DATA TABLE

Exp. S. No.	Core type	Loading rate (measured) (MPa/ms)	Static loading fractured pressure (calculated) (Mpa)	Fractured pressure (measured) (Mpa)
1	32.5 core	82.65	71.96	78.52
2		143.91		82.03
3		122.07		92.77
4		115.58		76.86
5		61.17		58.11
6		153.86		87.7
7	42.5 core	66.92	74.15	75.77
8		74.659		80.18
9		88.09		80.89
10		91.62		79.83
11		102.80		82.33
12		123.87		86.34
13	52.5 core	78.13	76.87	79.22
14		80.18		81.17
15		105.50		85.18
16		106.49		85.27
17		107.04		86.35
18		112.05		90.16
19		153.75		92.64

Regression and precision verifying of rock breakdown model under strong dynamic loading

Model regression: Table-1 reveals that the breakdown pressures of three different strengths' cores will grow with the loading rate's growing. Fig. 4 compares the relations between loading rate and four physical quantities including P_{df}, p_C, S and K separately as following, where P_{df} stands for dynamic loading break down pressure; p_C is the difference between the breakdown pressures under dynamic loading and static loading; S is the ratio of dynamic and static loading breakdown pressure difference and tensile strength; K denotes the ratio of breakdown pressures under dynamic and static loading conditions.

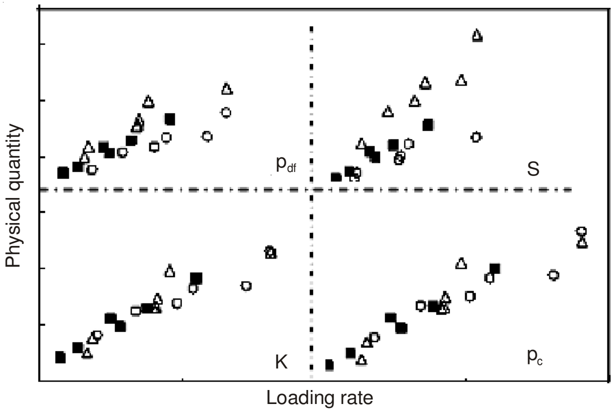


Fig. 4. p_{df}, S, K, p_c-loading rate relation scattered points

In order to use a uniform regression model to describe strong dynamic breakdown pressure of the three tensile rocks, it is necessary that all the data points should couple well and present excellent law. The above four kinds of relation graphs (Fig. 4) show that the relation between loading rate and p_c(p_c denotes the difference between the break down pressure under dynamic and static loading) can fit the above conditions well. Consequently, the breakdown pressure calculation formula under dynamic loading condition can be got by mathematical regression.

Through Fig. 5's mathematical regression, the logarithm formula between p_c and γ has the highest precision and the formula is shown in formula (VII),

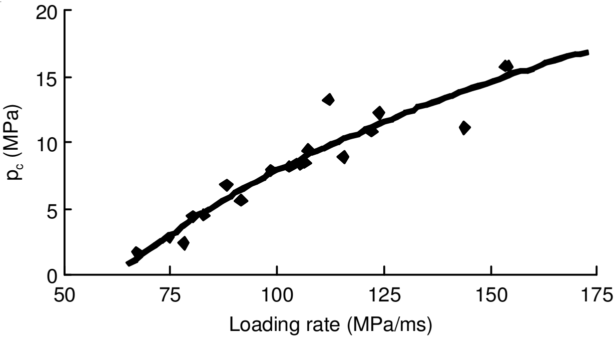


Fig. 5. Dynamic/static breakdown pressure (p_c)-loading rate (γ) curve

$$p_C = 163.637 \ln(\gamma) - 68.755 \qquad \text{(VII)}$$

Based on it, the break down pressure formula of different core under dynamic loading condition can be obtained and shown in formula (VIII),

$$p_{df} = p_f + 163.637 \ln(\gamma) - 68.755 \qquad \text{(VIII)}$$

where p_f, p_{df} stands for break down pressure under static and dynamic conditions separately and unit is MPa; γ stands for the loading rate under dynamic loading condition and its unit is MPa/ms.

Precision verification: Substitute the 19 groups data into relationship formula (VIII) and calculate, then the breakdown pressure under dynamic condition can be got. Compare them with the measured values in a chart form, as shown in Fig. 6.

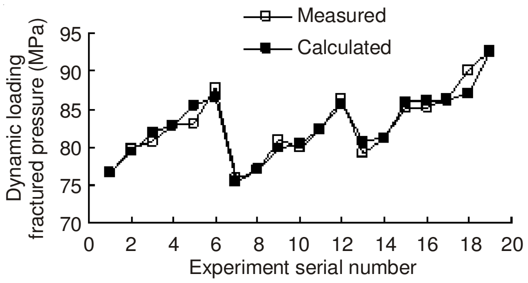


Fig. 6. Comparison chart of the calculated values and the experiment values of the dynamic breakdown pressure

Fig. 6 shows that the breakdown pressure under dynamic condition by calculation fits the one that measured well. The computation error is only 0.95 %, so it can accurately describe the breakdown pressure under dynamic loading of different wells.

Conclusion

(1) Verified by experiments, "the dynamic cracking simulation device" can reach different loading rates within 153.17 MPa/ms. It can also be adjusted quantitatively. Meanwhile, it can proceed water pressure blast cracking experiment directly on the simulation wellbore and can accurately simulate the loading process of real blasting pressure. Hence, it can provide the application basis for the experiment.

(2) Using this device to simulate three kinds of tensile strength cores, rock blast cracking experiment of 5 loading rates is conducted. Through regression analysis, the difference value of dynamic and static breakdown pressures under loading conditions has a logarithmic relationship with the loading rate. The regression model shows high precision by verification.

(3) In the design of blasting cracking, the synthesizing of the blasting burning model and the breakdown pressure calculation model under strong dynamic loading condition can help derive the minimum peak pressure, under which oil layer can be fractured successfully. In this case, the design of explosive load can be better optimized. Also, the universality and the success ratio of the implementwill be enhanced.

ACKNOWLEDGEMENTS

This work was supported by grants from the National Natural Science Fund of China (51104173).

REFERENCES

1. T. Zhang, X. Zhang and N. Li, High-Energy Perforation and Fracturing (HEPF)-Great Revolution of Perforation for 21st Century, SPE 64760 (2000).
2. Y.-S. Lin and J.-B. Jiang, *Drilling Production Technol.*, **30**, 48 (2007).
3. C.-B. Shi, *J. Xi'an Petroleum Inst.*, **15**, 17 (2000).
4. W.-K. Li, *J. Xi'an Eng. Univ.*, **22**, 60 (2000).
5. Y.-Z. Huang, *Fault-block Oil Gas Field*, **12**, 74 (2005).
6. D.L. Grote, S.W. Park and M. Zhou, *Int. J. Impact Eng.*, **25**, 869 (2001).
7. S.-S. Hu and D.-R. Wang, *Eng. Mechanics*, **18**, 115 (2001).
8. L. Zhan-lu and W. Qi-zhi, *Chinese J. Geotechnical Eng.*, **28**, 2116 (2006).
9. D. HunChen, The Fundamental Study of Explosive Fracturing within the Hydraulically Fractured Formations, College of Petroleum Engineering in China University of Petroleum, Dongying, Shandong (2006).
10. M. Hongxia and C. Dechun, *Petroleum Drilling Techniques*, **35**, 28 (2007).