Numerical Analysis of the Gas Injection Rate in Z12V190 Diesel Tail Gas Drilling

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Abstract: Diesel tail gas drilling (DTGD) is a type of gas drilling, which uses diesel tail gas (DTG) as a circulating medium. Its cost is slightly higher than that of air drilling, but is cheaper than those of nitrogen drilling and natural gas drilling. When the reservoir is drilled with DTG, just as nitrogen and natural gas, the DTG will prevent the burning and blasting of oil and gas in the bottom hole. In order to reduce costs, the DTG is often used in drilling the reservoir, to prevent the underground explosion. This paper analyzes the composition of the Z12V190 diesel exhaust, calculates oxygen mass percentage (OMP), and diesel tail gas rates (DTGR). At the same time, some minimum gas injection rate (MGIR) formulae, using the minimum kinetic energy method, have been updated and illustrated by an example. The analysis results are as follows: the increasing of OMP leads to the increasing of DTGR, the increasing of diesel load and air intake resistance of diesel (AIROD) leads to the decreasing of OMP. The increasing of Critical Point (CP) pressure and CP drill pipe (DP) annulus section area rises the increasing of CP MGIR. Comparing the DTGR curves and MGIR curves, we find that the DTGD is suitable for low pressure shallow wells as well as deep wells, with the condition that the OMP in DTG must be less than 12%. For low-pressure oil fields in China, the DTGD is feasible.

Keywords: diesel engine; tail gas; drilling; oxygen mass percentage; minimum gas injection rate; low-pressure

1 Introduction

DTGD is a type of special gas-based underbalanced drilling using DTG as a circulating medium, with the significant advantages of protecting oil/gas reservoirs,

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improving rates of penetration (ROP), preventing underground blasting, and reducing drilling costs, etc.[Shen et al (2009) and Mehta et al (1995)]. Theoretical and experimental studies pertaining to the DTGD technology have been conducted at the Southwestern Sichuan Basin and Southwest Petroleum Institute in China. The practical application of DTGD has achieved good economic results in the Sichuan oil and gas fields [Mehta et al (1995)]. However, DTGD is facing some problems: whether the DTGR meet the MGIR requirement or not, and whether the OMP meets the safety requirements of underground blasting [Wei et al (2008)] or not. This paper analyzes the Z12V190 DTG and safe OMP, calculates the DTGR and MGIR, and then compares the computed results, to reach some conclusions about the range of feasibility of DTGD .

2 Analysis of the Composition of DTG, and the Computation of DTGR

2.1 *Diesel Performance Parameters*

Most drilling sites use the high-power Z12V190B diesel, whose main performance parameters are as follows: 12 hours power 1200PS (882KW) [Wang et al (2004)], continuous power 1080PS (794KW), 209.4 $\pm$ 5% g/(kW·h) (0 # light diesel fuel consumption ratio), crude oil composition (C: 0.87, O: 0.004, H: 0.126), etc. The oxygen can be split and made to participate in the combustion reaction.

2.2 *An Analysis of the Composition of the DTG*

The main components of DTG are N_2, CO_2, H_2O, O_2 and a small amount of CO [Ilkilic (2009) and Ilkilic (2011)]. Excess O_2 is used to ensure a sufficient combustion, and hence DTG contains much of O_2. The differences of diesel-engine-use time, performance parameters, rotational speed and load lead to a measured exhaust OMP to fall in the range of 8% to 19% in actual drilling [Wei et al (2008)]. The higher load and greater AIROD lead to a lower tail gas OMP. The DTGD OMP for explosion limited safety falls in the range of 5% to 12% [Wei et al (2008)]. The upper limit of OMP for safety is 12% in low pressure unrestricted borehole, but the lower limit of OMP for safety ranges between 5% to 8% in high pressure flow blocked borehole. For on-site DTGD, the safe OMP can be increased to 14% [Wei et al (2008)] only with a low pressure unrestricted borehole. At the same time, increasing AIROD, improving the diesel load and removing the water vapor can reduce the OMP of DTG in the safety range of below 14%.

The diesel combustion reaction equations are shown as follows:

$$C + O_2 \overset{burning\,full}{\longrightarrow} CO_2 \uparrow \tag{1}$$

$$2H_2 + O_2 \overset{burning\,full}{\longrightarrow} 2\mathrm{H_2O} \uparrow \overset{cooling}{\longrightarrow} 2\mathrm{H_2O} : \text{ (liquid state) :} \tag{2}$$

$$2C+O_2 \overset{burning}{\longrightarrow} 2CO\uparrow \quad (3)$$

$$2CO+O_2 \overset{burning}{\longrightarrow} 2CO_2\uparrow \quad (4)$$

When the oxygen supply is sufficient, the equation (4) indicates that the vast majority of CO is converted into CO_2. The remaining small amount of CO is basically negligible [Alain et al (2008)]. Therefore, according to the law of conservation of mass, the above four equations can be equivalent to the reaction equation (5).

$$C_xH_yO_z+(x+\frac{y}{4}-\frac{z}{2})O_2 \overset{burning\ full}{\longrightarrow} xCO_2+\frac{y}{2}H_2O \quad (5)$$

2.3 The Computation of DTGR

Considering for example the 0th light diesel oil, the computed DTGR results will be analyzed. According to the mass percentage of main component and the corresponding molar mass, the molar numbers of the main components of 1 kilogram diesel fuel are calculated as follows [Hou and Gao (2011)]: the mole number of C: $x_{kmol}=\frac{0.78}{12}=0.0725$kmol; the mole number of H: $y_{kmol}=\frac{0.126}{1}=0.126$kmol; themole number of O: $z_{kmol}=\frac{0.004}{16}=0.00025$kmol; the mole number of O_2 for complete combustion: $O_{2kmol}=x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2}$. According to the mass conservation equation (5), the five calculation models have been deduced as follows:

$$[O_2\%]=\frac{[m-x_{kmol}-4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})-\frac{y_{kmol}}{2}]\times\frac{1}{5}\times 32}{\left\{\begin{array}{c}[m-x_{kmol}-4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})-\frac{y_{kmol}}{2}]\times 28.95\\ +4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})\times 28+x_{kmol}\times 44+\frac{y_{kmol}}{2}\times 18\end{array}\right\}} \quad (6)$$

$$[O_2\%]'=\frac{[m-x_{kmol}-4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})-\frac{y_{kmol}}{2}]\times\frac{1}{5}\times 32}{\left\{\begin{array}{c}[m-x_{kmol}-4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})-\frac{y_{kmol}}{2}]\times 28.95\\ +4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})\times 28+x_{kmol}\times 44\end{array}\right\}} \quad (7)$$

$$m=x_{kmol}+4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2})+\frac{y_{kmol}}{2} + \frac{\left[4\left(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2}\right)\times 28+44\times x_{kmol}+9y_{kmol}\right]\times O_2\%}{6.4-28.95\times O_2\%} \quad (8)$$

$$m'=m-\frac{y_{kmol}}{2}=x_{kmol}+4(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2}) + \frac{\left[4\left(x_{kmol}+\frac{y_{kmol}}{4}-\frac{z_{kmol}}{2}\right)\times 28+44\times x_{kmol}+9y_{kmol}\right]\times O_2\%}{6.4-28.95\times O_2\%} \quad (9)$$

$$M = \frac{\left\{ \begin{array}{c} \left[m - x_{kmol} - 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) - \frac{y_{kmol}}{2}\right] \times 28.95 \\ +4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) \times 28 + x_{kmol} \times 44 \end{array} \right\}}{m'} \tag{10}$$

Where, $[O_2\%]$ is the OMP of DTG with water vapor [Hou and Gao (2012)]; $[O_2\%]'$ is the OMP of DTG without water vapor; m is the total mole number of DTGR with water vapor [Hou and Gao (2012)], kmol; m' is the total mole number of DTGR without water vapor [Hou and Gao (2011)], kmol; M is the molecular weight of DTG without water vapor, kg/mol.

For DTGR, the safety limited OMP is 14% in practice, but 12% in theory. According to the theoretical limit for safety OMP and the above models, the calculated results are shown as below (Table 1). The minimum tail gas rate (MITGR) of one Z12V190 diesel is 67.4m^3/min, and the MXTGR is 82.7m^3/min. Normally, a drill crew can put at least one diesel in working order, and thus DTGR can basically meet the requirements of the MGIR. The deeper wells lead to the greater power for drilling. For two Z12V190 diesels, the MITGR is 134.7m^3/min, and the MXTGR is 165.4m^3/min; for three Z12V190 diesels, the MITGR is 202.1m^3/min, the MXTGR is 248.1m^3/min; for four Z12V190 diesels, the MITGR is 269.5m^3/min, the MXTGR is 330.9m^3/min.

The presented data in Table 1 are shown in Fig.1, and Fig.2. Each curve implies that the DTGR increases rapidly with the increasing of the OMP of DTG. Fig.2 is the segment of the Fig.1 with the OMP of DTG less than 13%. When the OMP of DTG is lower than 12% of the theoretical safety limit [Wei et al (2008)], drill crew may increase the DTGR for drilling by reducing AIROD and increasing the OMP of DTG.

3 Calculation of the MGIR , and its Analysis

3.1 MGIR Model Analysis

For gas drilling, if the gas annular velocity is too low, the cuttings of the drilling will slip to the bottom, to accumulate a head deposit and result in the choking phenomenon [Wang et al (2007)]. Drilling can not proceed further. Hence, the requirements for the volume of gas for drilling must not be less than the minimum gas velocity, at which the capacity to carry the cuttings is worse than at any other part of the annulus of the hole. In general, the closer to the well annulus bottom the DTG circulates, the lower its flow rate will be, the greater its pressure and density will be [Wang et al (2007)]. The density and pressure of DTG has a sudden drop at the junction of the drill collar and the DP, at which location there's the minimum carrying capacity (MCC) of the cuttings. The location with the MCC is often called the CP [Yuan et al (2007)]. Of course, in some special cases, the MCC does

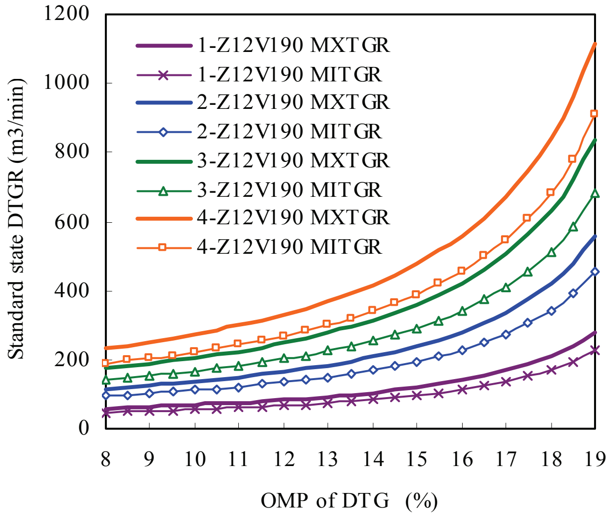

Figure 1: Relation curves about DTGR and OMP

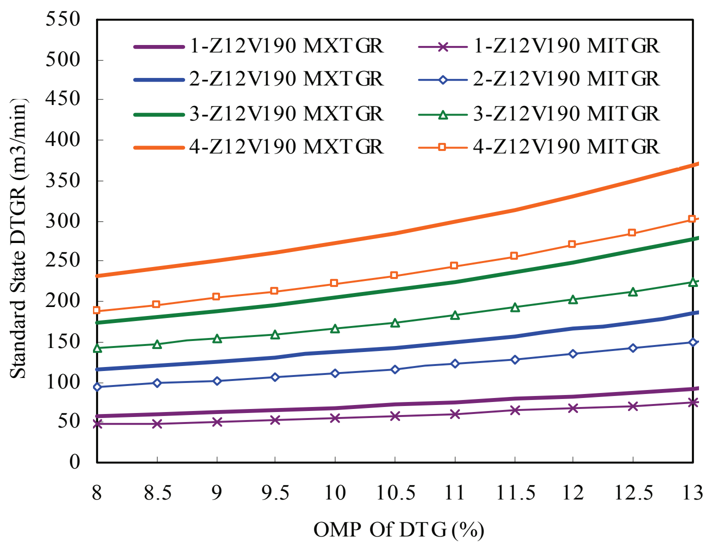

Figure 2: Relation curves about DTG and OMP (OMP is less than 13%)

Table 1: Diesel tail gas rates

$[O_2\%]'$ (%)	1 - Z12V190		2 - Z12V190		3 - Z12V190		4 - Z12V190	
	MXTGR (m^3/min)	MITGR (m^3/min)	MXTGR (m^3/min)	MITGR (m^3/min)	MXTGR (m^3/min)	MITGR (m^3/min)	MXTGR (m^3/min)	MITGR (m^3/min)
8.0	57.96	47.21	115.92	94.42	173.89	141.63	231.85	188.84
8.5	60.26	49.08	120.52	98.16	180.78	147.24	241.04	196.33
9.0	62.73	51.10	125.47	102.19	188.20	153.29	250.93	204.38
9.5	65.40	53.27	130.81	106.54	196.21	159.81	261.61	213.08
10.0	68.29	55.62	136.59	111.25	204.88	166.87	273.17	222.50
10.5	71.43	58.18	142.86	116.36	214.30	174.54	285.73	232.72
11.0	74.85	60.97	149.71	121.94	224.56	182.90	299.42	243.87
11.5	78.60	64.02	157.20	128.04	235.79	192.05	314.39	256.07
12.0	82.71	67.37	165.43	134.74	248.14	202.11	330.85	269.48
12.5	87.26	71.07	174.51	142.14	261.77	213.21	349.02	284.28
13.0	92.30	75.18	184.60	150.35	276.89	225.53	369.19	300.70
13.5	97.93	79.76	195.85	159.52	293.78	239.28	391.70	319.04
14.0	104.25	84.91	208.49	169.82	312.74	254.73	416.99	339.63
14.5	111.40	90.73	222.80	181.47	334.20	272.20	445.60	362.94
15.0	119.56	97.38	239.12	194.76	358.68	292.14	478.24	389.52
15.5	128.95	105.03	257.91	210.06	386.86	315.10	515.82	420.13
16.0	139.89	113.94	279.77	227.87	419.66	341.81	559.55	455.74
16.5	152.77	124.43	305.54	248.86	458.31	373.29	611.07	497.71
17.0	168.17	136.98	336.35	273.95	504.52	410.93	672.69	547.90
17.5	186.92	152.25	373.84	304.49	560.76	456.74	747.69	608.98
18.0	210.23	171.23	420.47	342.47	630.70	513.70	840.94	684.94
18.5	240.01	195.49	480.02	390.97	720.03	586.46	960.05	781.95
19.0	279.37	227.55	558.74	455.09	838.11	682.64	1117.49	910.18

not appear at the junction of the drill collar and the DP, but in the upper part of the junction [Tao et al (2010)]. Wherever the MCC happens to be, the MGIR can be calculated according to the different pressure of CP. There are many methods to calculate the MGIR, such as the minimum kinetic energy method, the minimum velocity method, and the analytical method [Tabatabaei et al (2008), Guo et al (2006), Johnson (1991), Carlos et al (1982) and Angel (1957)]. The analytical method considers more factors and is more comprehensive, but the calculation is relatively complex and not suitable to the field application. The minimum velocity method takes into account the interaction of gas and cuttings, and regards the sinking speed of the uniform solid particles as the critical speed. The MGIR is calculated by assuming that the volume of solid particles in the hole annulus is equal to the amount of drill cuttings [Angel (1957)]. Its difficulties take second place. The minimum kinetic energy method is the easiest method, but the method ignores the effects of the air density in the hole annulus [Hou and Gao (2011)]. Hence, some formulae to modify MGIR are derived by the analysis of DGT density at the CP, on the basis of the minimum kinetic energy method, such as formulae (11), (12), (13). The MGIR will be calculated with formulae (14), (15).

$$\rho_{01} = \frac{pM}{RT} = \frac{p}{RT} \frac{\left\{ \begin{array}{c} \left[m - x_{kmol} - 4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) - \frac{y_{kmol}}{2}\right] \times 28.95 \\ +4\left(x_{kmol} + \frac{y_{kmol}}{4} - \frac{z_{kmol}}{2}\right) \times 28 + x_{kmol} \times 44 \end{array} \right\}}{m'} \tag{11}$$

$$\rho_g = \frac{p_g \cdot T_{01}}{p_{01} \cdot T_g} \rho_{01} \tag{12}$$

$$v_g = \sqrt{\frac{\rho_{g0} \times v_{g0}^2}{\rho_g}} = \sqrt{\frac{\rho_{g0} \times v_{g0}^2 \times p_{01} \times T_g}{p_g \times T_{01} \times \rho_{01}}} \tag{13}$$

$$Q_g = \frac{\pi}{4} v_g \left(D_h^2 - D_{p0}^2\right) \tag{14}$$

$$Q_{g0} = Q_g \frac{pT_0}{p_0 T} \tag{15}$$

Where, ρ_{g0} is the gas density at standard atmospheric conditions, kg/m^3; ρ_g is the gas density at pressure P and temperature T, kg/m^3; ρ_{01} is the gas density at pressure p_{01} and temperature T_{01}, kg/m^3; Q_g is the MGIR at standard atmospheric condition, m^3/s; Q_{g0} is the MGIR at pressure p_{01} and temperature T_{01}, m^3/s; D_h is the wellbore diameter, mm; D_{p0} is the outside diameter of DP, mm; M is DTG molar mass, kg/kmol; R is general gas constant.

3.2 Calculation of an MGIR Example

For example, an oil well is drilled with DTG, the bit diameter is 200mm. The drill pipes (DP) are 5in, $4^1/_2$in, 4in, $3^1/_2$in, $2^7/_8$in and $2^3/_8$in respectively. The ground temperature is 20°C. The CP temperature in wellbore is 160°C. The CP pressure, which determines the MGIR, is the difference according to the CP depth. The MGIR is calculated from 1MPa to 11Mpa with 0.5MPa increments, according to (11)-(15). The results are shown in Table 2. The curves are drawn in Figure 3.

3.3 Analysis of Results

The graphical curve (in Fig.3 and Fig.4) shows:

Table 2: MGIR of CP with different DP and different pressure

CP Pressure p(MPa)	5in Q_{g0}(m^3/min)	$4^1/_2$in Q_{g0}(m^3/min)	4in Q_{g0}(m^3/min)	$3^1/_2$in Q_{g0}(m^3/min)	$2^7/_8$in Q_{g0}(m^3/min)	$2^3/_8$in Q_{g0}(m^3/min)
0.5	31.22	35.23	38.82	41.98	45.35	47.56
1.0	44.16	49.83	54.90	59.37	64.14	67.26
1.5	54.08	61.02	67.24	72.72	78.55	82.38
2.0	62.45	70.46	77.64	83.97	90.70	95.12
2.5	69.82	78.78	86.80	93.88	101.41	106.35
3.0	76.48	86.30	95.09	102.84	111.09	116.50
3.5	82.61	93.22	102.70	111.08	119.99	125.83
4.0	88.31	99.65	109.80	118.75	128.27	134.52
4.5	93.67	105.70	116.46	125.95	136.05	142.68
5.0	98.74	111.41	122.76	132.76	143.41	150.40
5.5	103.56	116.85	128.75	139.24	150.41	157.74
6.0	108.16	122.05	134.47	145.43	157.10	164.76
6.5	112.58	127.03	139.96	151.37	163.51	171.48
7.0	116.83	131.83	145.25	157.09	169.69	177.96
7.5	120.93	136.45	150.34	162.60	175.64	184.20
8.0	124.90	140.93	155.28	167.93	181.40	190.24
8.5	128.74	145.27	160.05	173.10	186.98	196.10
9.0	132.47	149.48	164.69	178.12	192.41	201.78
9.5	136.10	153.57	169.21	183.00	197.68	207.31
10.0	139.64	157.56	173.60	187.76	202.81	212.70
10.5	143.09	161.45	177.89	192.39	207.82	217.95
11.0	146.45	165.25	182.08	196.92	212.71	223.08

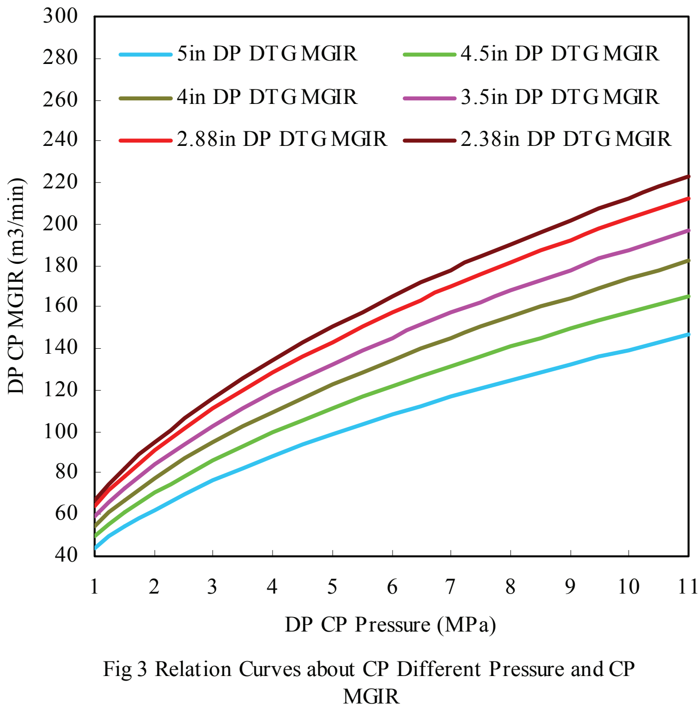

Figure 3: Relation curves about CP different pressure and CP MGIR

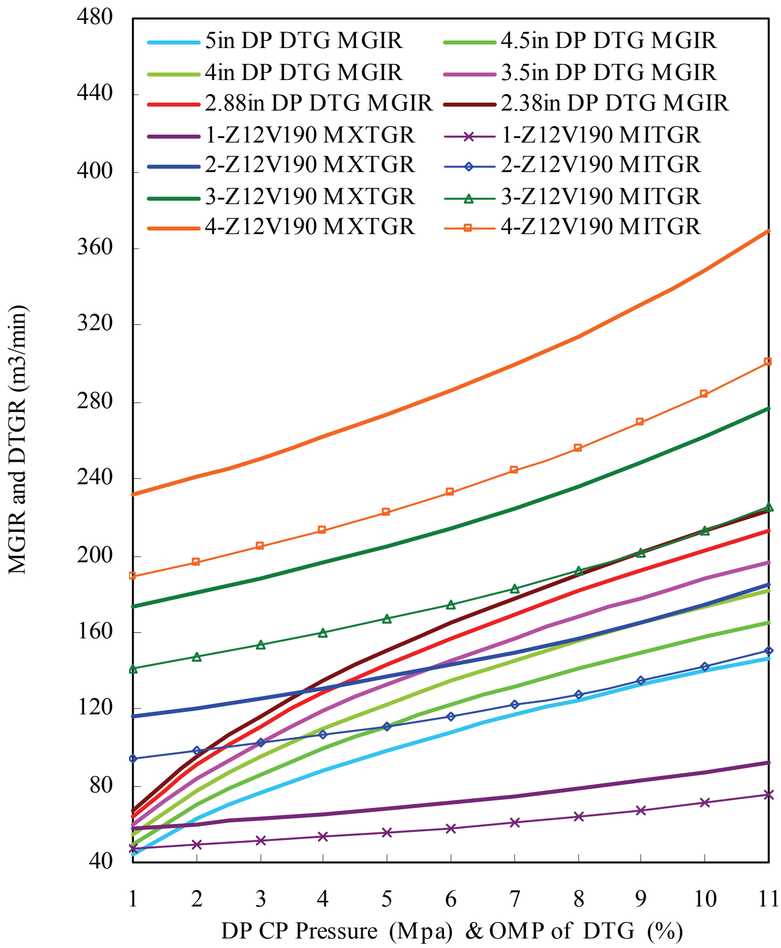

Figure 4: Relation curves about DTGR and CP MGIR with different pressure

1. Assuming that all the DP have the same diameter in the same diameter wellbore, while the pressure of CP gets higher, the MGIR of CP increases slowly.
2. Assuming that there are different diameters of the DP, and the same pressure at the CP, in the same diameter wellbore, the smaller diameter of DP led to the greater annular sectional area and the greater MGIR. Hence the larger diameter DP should be selected to meet the requirements of a smaller DTGR.
3. Only if the curve of DTGR is on the top of the curve of MGIR, the DTGR will meet the MGIR, and the DTGD can be done with the corresponding pressure. If it is to the contrary, the DTGD will not be undertaken.
4. The DTGD is not only suitable for low pressure shallow wells, but also for low pressure deep wells. The deeper wells and the smaller annular cross-sectional area lead to the greater CP pressure. On the contrary, the CP pressure will be smaller. According to our analysis of the computed results, the CP pressure range is determined by the DTGR and is shown in Table 3. The 1-Z12V190 DTGR is only suitable for drilling low pressure shallow wells, 2-Z12V190 DTGR improves the CP pressure range greatly, such as: 9MPa for the 5in DP CP pressure, 4MPa for the $2^3/_8$in DP CP pressure. The 2-Z12V190 DTGR can basically meet the pressure requirements from shallow well to deep well. The 3-Z12V190 DTGR can make the 5in-$3^1/_2$in DP CP pressure more than the maximum pressure 11Mpa. The $2^3/_8$in DP CP pressure reaches 9MPa. The 4-Z12V190 DTGR can make the CP pressure more than the maximum pressure 11Mpa with 5in-$2^3/_8$in DP and basically meet the pressure requirements from shallow well to deep well.

4 Field Application

The DTGD has achieved good economic results by practical application and in on-site testing in Sichuan oil and gas field in China. In Wei-100# well and Wei-27# well, OMP of two-Z12V190 DTG has been tested. The diesel have a long service life, three major repairs, poor performance and low load, so that the measured OMP is generally higher than 14%. The OMP of a 6135-type DTG has been tested under different conditions and the results are shown in Fig.5 and Fig.6 [Wei et al (2008)]. With the increasing load, the OMP is decreasing. As long as the diesel has a full load, the OMP can be reduced to below 14% to meet the practical safety requirements (Fig.5). With the increasing of the AIROD, the OMP is decreasing. Therefore, the OMP can be reduced to below 14% by increasing AIROD (Fig.6). Due to the complexity and variability of the DTGD, the methods of control of actual load is difficult, the OMP will be adjusted mainly through increasing AIROD.

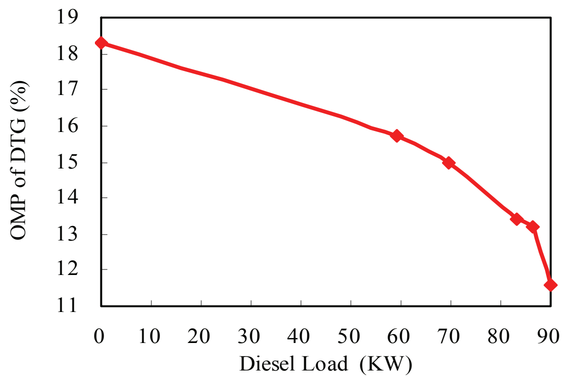

Figure 5: Relation curve about load and OMP of DTG

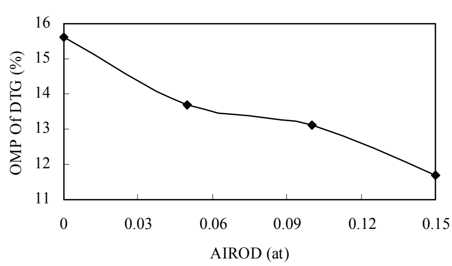

Figure 6: Relation curve about AIROD and OMP of DTG

Table 3: N-Z12V190 DTGR at corresponding DP CP maximum pressure

Number Of Z12V190	N-Z12V190 DTGR at Corresponding DP CP Maximum Pressure (MPa)					
	5in DP	$4^1/_2$in DP	4in DP	$3^1/_2$in DP	$2^7/_8$in DP	$2^3/_8$in DP
1	≤ 2.5	≤ 2	≤ 1.5	≤ 1	≤ 1	≤ 1
2	≤ 9	≤ 7	≤ 6	≤ 5	≤ 4	≤ 4
3	>11	>11	>11	>11	≤ 10	≤ 9
4	>11	>11	>11	>11	>11	>11

Description:

"$\leq$ n" indicates that the maximum pressure at corresponding DP CP can reach "n" MPa.

"$>$ 11" indicates that the maximum pressure at corresponding DP CP is more than 11MPa.

Based on a comparative analysis of DTGR and MGIR, the DTGD has been used in low-pressure wells with the low-pressure structure, such as Sichuan Weiyuan structure, Xichang Qiliba structure, Chengdu to Longquan mountain structure belts. A great deal of wells have been finished DTGD. For example, 6 low-pressure wells with the 0.4-0.6 pressure coefficient have been finished with the cutting of windows for side track drilling, a low-pressure development gas well has been drilled, and several tens of wells with a severe loss of circulation during drilling a weak zone have been drilled established circulation (including 2 overseas wells and many negative pressure wells) [Wei et al (2008)]. The DTGD can be applied in deep and shallow wells, such as Qiliba-1# Well from initial open to 705m depth, Xin-24# Well from 1540m to 1575m with formation pressure coefficient of 0.3 to 0.4, Sanhuang-2# Well from 1000m to 1500m with formation pressure coefficient of 0.85. Practice has proved that: DTGD has not only played an active role in improving ROP, discovery and reservoir protection, enhancing oil recovery, but also achieved good technical and economic benefits [Iscan (2007)].

5 Conclusions

1. The Z12V190 DTGR increases with the increasing of the OMP of DTG. In order to make the OMP lower than the blasting limits of 12% to ensure safe drilling, the AIROD and the load must increase. When the OMP is much lower than 12%, the AIROD decreases so that the DTGR increases.

2. The CP MGIR increases with the increasing of CP pressure. Similarly, the CP MGIR increases with the increasing of annular sectional area. So the

DTGR is adequate, small-diameter DP can be chosen to obtain a big annular sectional area to meet low pressure wells, and vice versa.

3. The DTGD is not only suitable to the low-pressure shallow wells, but also suitable to the low-pressure deep wells. The deeper wells lead to the greater pressure of CP. The shallower wells lead to the smaller pressure of CP. The 1-Z12V190 DTGR is only suitable for drilling low pressure shallow wells, and 2-Z12V190 DTGR improves the CP pressure greatly and can meet basically the pressure requirements from shallow wells to deep wells. The 3-Z12V190 DTGR can make the CP pressure larger than the maximum pressure (11Mpa) with 5in-$3^1/_2$in DP. The 4-Z12V190 DTGR can make the CP pressure larger than the maximum pressure (11MPa) with 5in-$2^3/_8$in DP and meet basically the pressure requirements from shallow well to deep well.

4. DTGD is feasible for low-pressure oil & gas fields. The DTGD has not only played an active role in improving drilling speed, discovery and reservoir protection, and enhancing oil recovery, but also achieved a significant technical and economic benefits, hence it shows a great prospect for broader application.

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