

二氧化碳压裂供液系统设计

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摘要: 在 CO₂ 压裂技术早期应用过程中, 使用常规 CO₂ 槽车和 CO₂ 增压泵车作为压裂车的主要供液设备, 施工过程中由于增压泵车的抽吸作用和地面管路的摩阻, 使得 CO₂ 槽车中处于临界状态的液态 CO₂ 部分气化, 导致施工排量难以提高且极不稳定, 影响施工的正常进行。针对液态 CO₂ 气化导致的压裂装备走空泵、排量波动、持续供液难等问题, 主要从气体增压装置、控制系统、CO₂ 储罐及地面管汇四部分对供液系统进行设计, 通过现场多井次的应用表明该供液系统可大幅提高施工排量, 保持整个施工过程的排量平稳, 为 CO₂ 压裂技术的现场成功应用奠定了坚实的基础。文章主要从技术分析、系统功能、系统结构、现场应用四个方面介绍该供液系统。

关键词: CO₂ 压裂; 供液系统; 气体增压; 气化

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在低渗透油气藏增产开发中, CO₂ 压裂技术作为一种无水压裂新技术, 以无水的液态 CO₂ 作为压裂介质, 具有低伤害、易返排、造缝容易、环保等优点, 适合低压低渗透、致密及水敏性强的复杂岩层, 对油气层伤害严重、含水率较低的储层改造效果良好, 可大幅提高单井产量^[1-4]。

在 CO₂ 压裂技术前期应用中, 使用常规的 CO₂ 运输槽车、CO₂ 增压泵车作为压裂车的供液组合装备。通过前期多井次的现场试验, 发现采用这种供液方式存在以下四个方面的问题:

(1) 施工过程中增压泵车的抽汲作用和管路摩阻使地面供液管线中的液态 CO₂ 部分气化, 导致压裂车走空泵, 排量难以提高且极不稳定, 容易造成砂堵^[5-6]。

(2) 使用的常规 CO₂ 运输槽车气、液相接口尺寸较小, 无法满足 CO₂ 压裂施工排量要求。

(3) 由于管线摩阻影响, CO₂ 槽车液位下降的速度不一致, 若其中一台或多台槽车内的液态 CO₂ 提前用尽, 会导致气体进入地面管线, 造成压裂车走空泵。

(4) 根据目前 CO₂ 压裂施工规模, 每次所需的 CO₂ 槽车数量 10 余台, 由于常规 CO₂ 运输槽车为大型半挂车, 因此对井场面积有较高要求。

针对上述问题, 通过设计制造专用的 CO₂ 储罐, 引入气体增压技术, 开发全自动供液控制系统, 形成一套完善的供液系统, 完全解决了 CO₂ 压裂施工中存在的供液问题。

一、技术分析

防止液态 CO₂ 气化是实现大排量 CO₂ 压裂施工的关键。依托于中国石油天然气集团公司油气藏改造重点实验室-二氧化碳压裂增产研究室, 在室内试验平台对 CO₂ 的特性进行研究, 从理论上分析了气体增压的原理。

1. 理论计算

液态 CO₂ 在管中为气-液混合的两相流动, 模拟现场施工情况, 当施工管线内 CO₂ 温度 $t = -20^{\circ}\text{C}$, 施工压力 $p = 1.9 \text{ MPa}$ 时气、液 CO₂ 的密度分别为 $\rho_c = 51.41 \text{ kg/m}^3$, $\rho_l = 1\,029.9 \text{ kg/m}^3$, 由式(1)

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~式(4)可以计算得到管线中 CO₂ 气液相体积比为 V_c/V_l≈1.4,说明在现场施工过程中由于增压泵车的抽吸和管路的摩阻,液态 CO₂ 的气化现象非常严重。

$$U_c = \frac{m_r \alpha_c}{\rho_c A} \tag{1}$$

$$U_l = \frac{m_r (1 - \alpha_c)}{\rho_l A} \tag{2}$$

$$U_c/U_l \approx 1.4 \tag{3}$$

$$\alpha_c = \frac{1.4 \rho_c}{1.4 \rho_c + \rho_l} = 0.0653 \tag{4}$$

式中:m_r—管内两相流总流量,kg/s;

U_c、U_l—管内 CO₂ 气、液相流速 m/s,通常 U_c/U_l = 1.4;

α_c—管内气相 CO₂ 的质量分数;

A—管段截面积,m²;

ρ_l—液态 CO₂ 密度,kg/m³。

2. 气体增压原理

液态 CO₂ 常规情况下处于临界状态,此时 CO₂ 状态与图 1 中 OC 段曲线一致^[4],假设此时 CO₂ 位于图 1 中的点 p₂。

液态 CO₂ 输送到压裂车的过程中,由于管路沿程摩阻及增压泵车的抽汲导致液态 CO₂ 产生压力降,部分液相转换为气相,造成 CO₂ 供液能力下降、压裂车走空泵、施工排量降低、排量波动。

气体增压就是在处于临界状态下的 CO₂ 之上使用增能气体进行增压,气体增压作用后,设此时 CO₂ 位于图 1 点 p₃,若 Δp₁ = p₃ - p₂、增压泵车的抽汲和地面管路的摩阻转换为当量压头损失为 Δp₂,那么只要保证气体增压后 Δp₁ > Δp₂,就能确保 CO₂ 始终处于液相状态,即图 1 中 D 区。

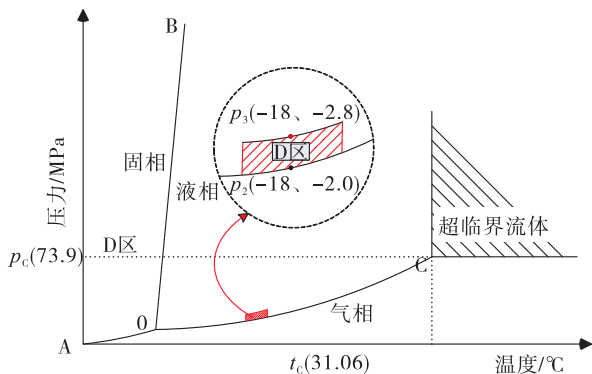


图 1 气体增压原理

二、系统功能

1. 气体增压功能

(1) 主要由气体增压装置实现该功能,利用增

能气体稳定的物理特性给 CO₂ 储罐加压,防止液态 CO₂ 从储罐输送到压裂车的过程中因气化而导致压裂车走空泵。

(2) 使用增能气体驱替储罐内的液态 CO₂,使压裂车得到持续且稳定的供液。

2. CO₂ 储罐供液控制功能

CO₂ 储罐供液控制系统地面设备包括 CO₂ 储罐、地面管汇,主要满足以下功能:

(1) 采集各 CO₂ 储罐压力参数,自动控制输出压力调节阀开度(如图 2),使最大压力稳定在一定范围内。

(2) 系统采集各 CO₂ 储罐液位参数,通过计算和比对,控制 CO₂ 储罐流量调节阀(如图 2)至适当开度以保证施工过程中各储罐的液位同步下降。

(3) 控制系统将采集到的气体增压装置各种电测参数、CO₂ 储罐压力及液位等传送至仪表车。

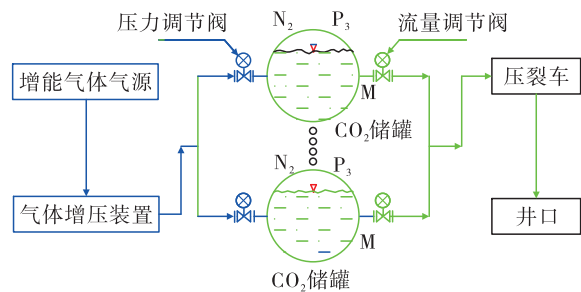


图 2 气体增压流程简图

三、系统结构

1. 气体增压装置

气体增压装置分为两条管路,对称分布,减压阀前端为高压管汇区(图 3 中 A 区),减压阀后端为低压管汇区(图 3 中 B 区),两条管路之间通过连通阀连通,出口主管路上设置有流量计、压力传感器。施工过程中,气体增压装置的高压入口经减压阀,转换成低压气体,提供给 CO₂ 储罐。

2. CO₂ 储罐

CO₂ 储罐用来存放 CO₂ 液体,为压裂车供液。液相输出为 Ø101.6 mm 接口,能满足大排量施工要求;相比 CO₂ 槽车,其占地更小,便于井场摆放。

3. 控制系统

控制系统对气体增压装置、CO₂ 储罐、各项电测参数实时监测,在施工过程中自动控制 CO₂ 储罐和压力调节阀、流量调节阀开度从而控制压力和液位,连接至仪表车上的手提控制箱,在仪表车上实现对

气体增压装置、CO₂ 储罐、地面管汇远程控制。

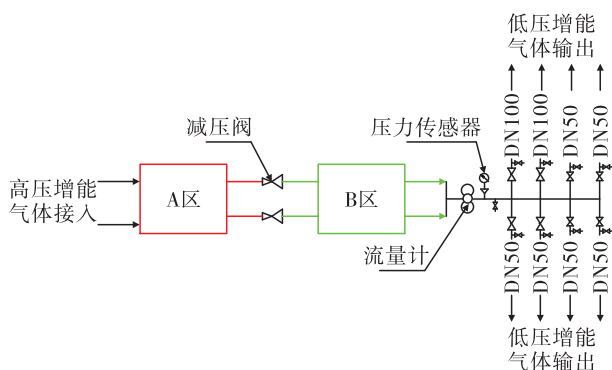


图 3 气体增压装置管汇系统

4. 地面管汇

地面管汇是气、液相介质的流动通道,指施工过程中的低压区内所有管线和分配器,主要包括气体增压管汇(如图 4 蓝色线)、上液管汇(如图 4 绿色线)。气体增压管汇内介质为增能气体,以串连方式为 CO₂ 储罐增压;上液管汇内介质为液态 CO₂,为压裂车供液。

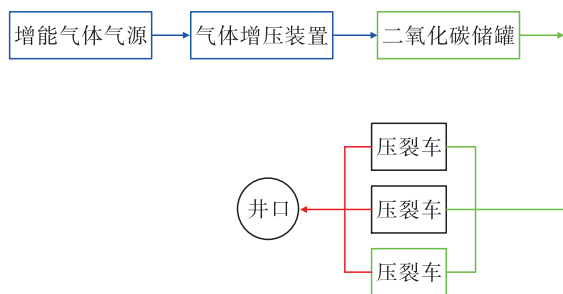


图 4 地面管汇布置

四、现场应用

供液系统自 2017 年 4 月开始先后在长庆油田公司、延长石油集团进行了多井次的现场应用,应用结果表明该系统能从根本上解决压裂车走空泵、排量波动、CO₂ 供液能力有限的问题。

如 2017 年 8 月在长庆苏里格气田试验井 3 进行的 CO₂ 干法加砂压裂现场试验,该井井深 3 420 m,采用油套同注、环空加砂方式压裂,压裂施工过程中顺利,压裂施工参数如表 1 所示。此次施工刷新了国内气田相同工艺井深之最、单井单层加砂量之最、环空排量之最、施工砂比之最,最高砂比达到 15%。

该供液系统控制 CO₂ 储罐压力在 2.1 MPa,从图 5 可知气体增压平稳,CO₂ 储罐出液稳定;压裂施工环空排量始终稳定在 3.7 ~ 4.5 m³/min,大排量

为大砂比施工奠定了基础,有效改善了压后效果。

表 1 试验井 3 压裂施工参数统计表

排量 / (m ³ · min ⁻¹)	加砂量 / m ³	平均砂比	入地总液量 / m ³
5.0 ~ 5.5	20	10.3%	426

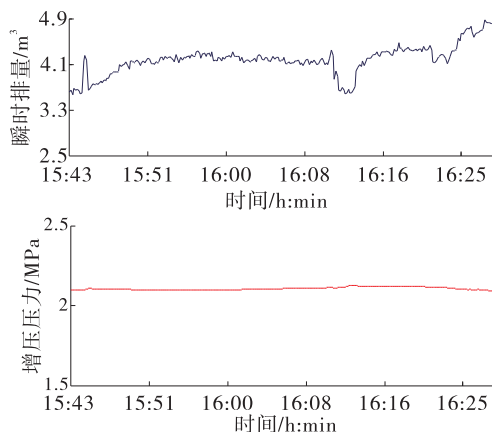


图 5 气体增压系统增压压力、施工排量曲线

五、结论

- (1) 该供液系统从根本上解决了 CO₂ 压裂施工过程中液态 CO₂ 气化而导致的压裂车走空泵问题。
- (2) 该供液系统保证了施工过程中持续、稳定为压裂车供液。
- (3) 该供液系统现场试验成功为今后大砂比、大排量 CO₂ 压裂技术的推广应用提供了技术支撑。
- (4) 该供液系统可应用于 CO₂ 伴注压裂、CO₂ 泡沫压裂、增能压裂,保证大排量施工的同时提高液态 CO₂ 利用效率。

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(编辑:刘英)

shale and fracturing fluid, and it is not clear on ion source in fluid flowback. In this article, by measuring ion type and content of fluid after shale and fracturing fluid interaction, the quantitative analysis of the result of the water quality analysis is carried out, calculating the contribution rate of various substances in solution salinity in some block. Ion source in fluid flowback and ion exchange mechanism is studied in shale gas well. And through the calculation of ionic strength, total hardness and the measurement of particle size, the stability of gel fracturing fluid and the relationship between the both were analyzed. The research results show that ion exchange will happen after the action of shale and fracturing fluid, all kinds of soluble inorganic salt dissolution in reservoir and clay minerals is the main source of ion in flowback fluid. There are filled of a lot of soluble salt in shale natural fracture and pore, soluble salt content in the shale accounted for a larger proportion. The stability of colloids is controlled by the surface charges. The greater ionic strength is, the more unstable glue solution is, minerals is the more inclined to gather, in turn, lead to crack or hole damage, the gas well capacity will be affected. In optimal design of shale gas, according to the results of ion type, concentration, and the stability of colloids after the action of the shale and fracturing fluid to optimize fracturing fluid formula, as far as possible to prevent the generation of precipitation.

Key words: shale gas, ionic exchange, ionic strength, colloidal stability, soluble salt, electrical conductivity

FRACTURING TECHNOLOGY OF SUBSEA GAS HYDRATE RESERVOIR

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Abstract: Due to the complexity of deep-sea gas hydrate mining, there is no mature exploiting technology in the world as a whole, with low single well production, short continuous time and poor economic benefits, so it is necessary to study the process method of efficient exploitation of gas hydrate reservoirs. In this study, the technology of fine layered cold water fracturing in vertical wells is proposed. Geological and mechanical parameters are investigated in detail. The gas hydrate reservoir has low tensile strength and elastic modulus, it can be fractured. Aiming at the gas hydrate reservoir, this paper compares the applicability of hydraulic slotting technology, hydraulic jet radial horizontal well technology and hydraulic fracturing technology, and recommends the use of hydraulic fracturing technology to increase production. The fracturing principle of subsea gas hydrate reservoir is established, and the fracturing technology without proppant is recommended. This article proposes the fracturing fluid technology of low-temperature and low-resistance seawater. When the temperature of fracturing fluid injected into wellhead is equal to the reservoir temperature 15.4°C, the fracturing fluid temperature round the formation can be ensured to be less than a certain range of reservoir temperature. The adaptability of various layered fracturing technologies is analyzed, and it is recommended that perforated bridge plug or coiled tubing hydraulic sandblasting perforating fracturing technology. The construction parameters of single fracture are designed.

Key words: natural gas hydrate, parameters, layered fracturing, low temperature fracturing fluid, technology

DEVELOPMENT AND APPLICATION OF REAMING WHILE DRILLING BASED ON RFID CONTROL TECHNOLOGY

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search Institute of Petroleum Engineering, Beijing 100101, China; 3. Fifth Drilling Engineering Division of CNPC Bohai Drilling Engineering Co., Ltd.), *DPT* 43(4), 2020:71–74

Abstract: In order to solve the problems of conventional reamer while drilling in practical application, the paper designed a kind of reamer while drilling based on RFID technology. The commands are wireless transmitted and received by RFID communication system, and hydraulic executive system control the action of reamer blade to realize the downhole reaming operation. In the process of tool design, by installing ferrite shielding ring outside the RFID antenna, the problem of weakening the magnetic field intensity of the antenna caused by downhole metal eddy current is solved, it ensures the reliable reception of commands by the downhole RFID control system. The maximum pressure of hydraulic executive system is determined by theoretical calculation and AMESim simulation, which provides a theoretical basis for optimum selection of solenoid valve and pressure design of hydraulic circuit, so that the reamer blade can be reliably locked. The designed RFID reamer while drilling has been successfully used in 4 wells, which verifies the reliability and stability of the tool.

Key words: reamer while drilling, RFID, electromagnetic shielding, hydraulic locking

DESIGN OF LIQUID SUPPLYING SYSTEM IN CARBON DIOXIDE FRACTURING

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Abstract: In the early application of carbon dioxide fracturing technology, the conventional carbon dioxide tank car and carbon dioxide booster pump are used as the main liquid supply equipment for the fracturing car. In the process of fracturing, the suction function of the booster pump and the friction of the ground pipe make the liquid carbon dioxide gasifying partly, which causes the displacement is improved difficultly and unstable extremely. In view of the problems of fracturing equipment, such as the gasification of liquid carbon dioxide in pump, the fluctuation of displacement and the difficulty of continuous liquid supply, the liquid supply system is designed mainly from four parts, including gas pressurization equipment, control system, carbon dioxide storage tank and the ground pipe line. The application of multi wells in the field shows that the liquid supplying system can greatly improve the construction displacement and ensure stable displacement during the construction process. It laid the solid foundation for the successful application of carbon dioxide fracturing technology. This paper mainly introduces the liquid supply system from four aspects: technical analysis, system function, system structure and field application.

Key words: carbon dioxide fracturing, liquid supply system, gas pressurization, gasification

STUDY ON HIGH EFFICIENCY COOLING TECHNOLOGY OF HEAVY OIL STEAM STIMULATION

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Abstract: In order to meet the technological requirements of steam huff and puff production and exploitation of heavy oil in an offshore well, the heavy oil to be mined (110°C ~ 200°C) will be cooled to meet the safety production demand (50°C-