

Selection of Diameter of Spherical Tag in Fracturing Process which Use Radio Frequency Identification Technology

Shengtong Yuan, Jian Chen

School of Mechatronic Engineering, Southwest Petroleum University, Chengdu 610500, China

Abstract: *In recent years, multi-stage fracturing technology of horizontal well with intelligent sliding sleeve based on radio frequency identification technology is gradually applied to the field of horizontal well fracturing. The selection of diameter of spherical tag become a new problem because the new process need tags have slow speed when pass through the smart sleeve and these spherical tags could not come into being blocked by themselves when fracturing fluid backflow. This paper took some researches of diameter selection of the spherical tag through these two aspects. The numerical simulation and mechanics analysis results show that, the smaller diameter of RFID tag, the higher recognition of signal within a certain range. However the diameter of RFID tag should not be too small considering the blocking in fracturing fluid backflow process. Spherical tag moving in the tubing which diameter is 76mm carried by fracturing fluid, the diameter of spherical tag select 48mm is suitable.*

Keywords: Diameter selection; Spherical tag; Fracturing; RFID; Numerical simulation

1. Introduction

In order to improve recovery efficiency of low permeability oil reservoirs and shale gas reservoirs, the technology of ball injection sliding sleeve in horizontal well staged fracturing have been widely promoted and applied^[1]. The basic principle of horizontal multi-stage fracturing^[2,3] is dividing horizontal section into several segments using packer and sliding sleeve according to the needs of reservoir development, and open corresponding sliding sleeve by throwing balls with different size from small to big in fracturing and acidizing processes, yet the fracturing series is limited as the hole size can't be large. With the proposal of the goals for industrial upgrading and optimization of resources exploitation, horizontal multi-stage fracturing gradually develops to a longer horizontal section, and the technology of ball injection sliding sleeve in horizontal well staged fracturing can't complete all the fracturing operation by place in pipe column at a time.

In recent years, multi-stage fracturing technology of horizontal well with intelligent sliding sleeve based on RFID (Radio Frequency Identification) is gradually applied to the field of horizontal well fracturing. Different information code are embedded into the RFID intelligence sliding sleeve and electronic tag through computer, and form the only corresponding relations with each other, if a particular layer needs fracturing, then deliver the corresponding spherical RFID tag, and when the RFID tag is pumped to the position of the intelligence sliding sleeve in that layer, the RFID communication unit obtains signal from RFID tag, the control command is outputted after communication units interpret it, then triggering the internal power plant, driving actuator moving, turning on or off the sliding sleeve.

In fracturing process which use radio frequency

identification technology, the diameter of spherical tag is uniform. So that smart sleeve staged fracturing tool based on RFID can improve the fracturing series of horizontal section of a single well, and reducing the cost of the shale gas development in fracturing stage. The selection of diameter of spherical tag become a new problem because the new process need tags have slow speed when pass through the smart sleeve and these spherical tags could not come into being blocked by themselves when fracturing fluid flow back. This paper took some researches of diameter selection of the spherical tag through these two aspects.

2. Force Analysis of Spherical Tag carried by fracturing Fluid

This section research the force of spherical tags with different diameter in fracturing fluid of horizontal section through COMSOL software. Fluid force acting on moving object mainly includes viscous force, differential pressure acting force and wave-making resistance these three types.

The force of fracturing fluid carry the spherical tag in the horizontal section is mainly differential pressure acting force. In the movement process of the spherical tag in the horizontal section carried by fracturing fluid, the influence factors of the thrust on the spherical tag are viscosity coefficient of fluid, diameter ratio of the spherical tag and tubing, the fluid velocity and so on. But, comparing with viscosity coefficient of fluid, the diameter ratio of the spherical tag and tubing has a greater influence to the thrust; the fluid velocity is more affected by the pump rate of fracture fluid at well head. The following are force analyses of the spherical tag with different diameter of 20mm, 30mm, 40mm, 50mm, 60mm, 70mm in the tubing which diameter is 76mm.

2.1 Numerical Simulation by COMSOL

(1) Flow channel model establish

We analyze the forces of spherical tags with different diameter of 20mm, 30mm, 40mm, 50mm, 60mm, 70mm in the tubing which diameter is 76mm, the flow channel model

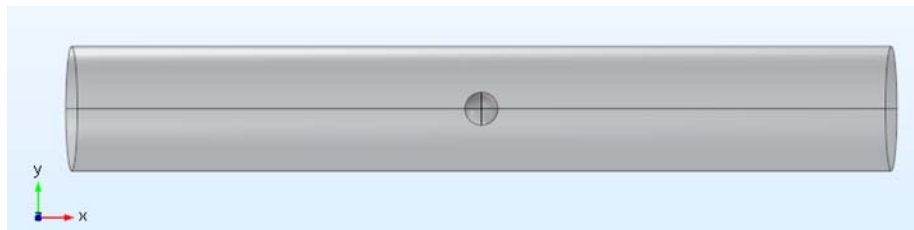


Figure 1: Flow channel model of numerical simulation

(2) Physical field settings of numerical simulation

In the simulation study, the density of fracturing fluid in horizontal section and RFID tag is set to 1000 Kg/m^3 , the viscosity coefficients of fluid is set to 100 mPa/s .

Fluid Simulation Analysis Inlet boundary conditions are defined as fluid flow conditions at the inlet. Commonly used fluid flow inlet boundary conditions in COMSOL are velocity inlet conditions, pressure inlet conditions, and mass flow inlet conditions^[4-6]. The velocity inlet boundary conditions can be adopted by this numerical simulation. The velocity is set to 1.838 m/s .

Those Common boundary conditions for fluid flow in COMSOL are velocity outlet conditions, pressure outlet conditions, and open boundaries^[7-9]. The boundary conditions of the pressure outlet are selected by incorporating the field fracturing process, and the pressure is set as the fracturing pit bottom pressure: 80 MPa .

(3) Meshing

Combining the result of grid independence validation, the accuracy and time cost, it's better to choose the number of grid in the flow field model at around 240,000. Mesh subdivision is applied to spherical tag.

(4) Calculation and post-processing

COMSOL result processing can be used to swiftly solve the mathematic problems by doing integral, averaging, calculating extreme value and so on toward the results from selected domain, surface, line, and point. It also contains the post-processing function of "the accurate integral about reaction force and flow", which is expressed by "reacf ()". Through the method of "sum up the nodes" in surface integral to solve the "reacf ()" can calculate the reaction force and reaction flow in the selected face. In the fluid flow, the reaction force of the fluid towards the target surface can also be solved by "reacf ()", in the whole solution -reacf (u), - reacf (v), - reacf (w) are respectively presenting the reaction force of the fluid towards the target surface from X, Y, Z directions.

After the modeling, physical field setting, meshing, solver setting, and calculation, we can get the stress of static tag in x

corresponding to the tag with a diameter of 20mm, as shown in Figure 1. In horizontal section RFID tag and fluid have the same density, the tag is positioned in the center axis of the flow channel model.

direction by solving -reacf(u).

2.2 Force analyses of spherical tags with different diameters

The thrust on spherical tags with different diameters can be obtained by COMSOL, the nephogram of force is shown in Figure 2. The data of "-reacf(u)" which are resultant force in the x direction are shown in table 1.

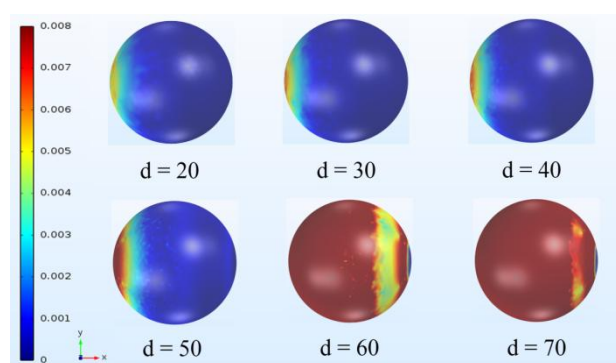


Figure 2: Nephogram of thrust on spherical tags with different diameters in 76mm tubing

Table 1: Resultant force in the x direction of spherical tags with different diameters

Diameter (mm)	20	30	40	50	60	70
Resultant force in the x direction (N)	0.101	0.363	0.885	1.804	10.269	58.377

From table 1, the axial force on spherical tag with different size is different, which increases along with the increasing of diameter of tag and increases rapidly as the diameter of tag is approaching the diameter of tubing.

In multi stage fracturing technology of horizontal well based on RFID, the larger velocity of RFID tag when passing by sliding sleeve will lead to the lower signal recognition raised in the research background of this paper. So in a certain range, the diameter of tag is smaller, the less thrust, the better signal recognition.

3. Study of Blocked Tag when Fluid Flowback

3.1 Mechanics analysis for blocked tag

Fracturing fluid flowback is an important part of hydraulic fracturing technique, proper velocity of flowback is one important factor to increase oil output. But the situation that tag been blocked with each other appear at the scene of flowback, which results from that tag pushing against each other make the thrust on tag applied by fracturing fluid less than the friction between tag and the wall of tubing. The forces on two blocked tags in static state are shown as Figure 3.

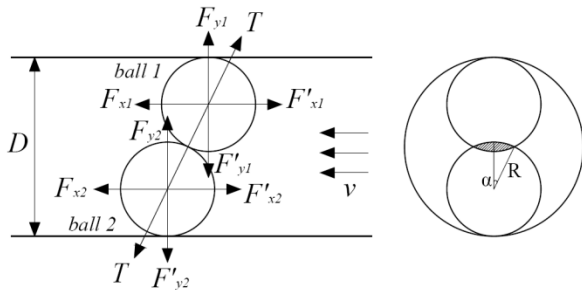


Figure 3 Free-body diagram of two blocking spherical tags

The component forces applied to two tags are expressed as equation (1) and equation (2) respectively.

$$\left. \begin{aligned} F_{x1} &= F_{w1} \\ F'_{x1} &= T \sin \alpha + f = T \sin \alpha + \mu N \\ F_{y1} &= F_F + T \cos \alpha \\ F'_{y1} &= G + N \end{aligned} \right\} \quad (1)$$

$$\left. \begin{aligned} F_{x2} &= F_{w2} + T \sin \alpha \\ F'_{x2} &= f = \mu N \\ F_{y2} &= F_F + N \\ F'_{y2} &= G + T \cos \alpha \end{aligned} \right\} \quad (2)$$

F_{w1} , F_{w2} — the axial thrust on tag 1 and 2 from fracturing fluid;

f — the friction between tag and wall of tubing,
 $f = \mu N$, μ represents friction coefficient, N represents the pressure apply to tag ball from wall.

F_F — buoyancy apply to tag from fracturing fluid.

G — the gravity of tag ball.

See tag 1 and 2 as a system, the force along the axis direction have following balance:

$$F_{w1} + F_{w2} = 2\mu T \cos \alpha \quad (3)$$

Connect equation (1), (2), (3), simplified as:

$$F_{w2} = F_{w1} \frac{\mu \cos \alpha - \sin \alpha}{\mu \cos \alpha + \sin \alpha} \quad (4)$$

According to the description of differential pressure force and the formula of air drag showing as $f = \frac{1}{2} C \rho S v^2$, we can think that the thrust apply to tag from fracturing fluid

and the frontal area of tag towards liquid is proportional, that is:

$$F_w \propto S \quad (5)$$

The following equation (6) can be obtained from figure 3:

$$\frac{S_{b1}}{S_{b2}} = \frac{S_R}{S_R - S_s} = \frac{\pi R^2}{\pi R^2 - 4\pi R^2 \frac{\alpha}{2\pi} + 2R^2 \sin \alpha \cos \alpha} \quad (6)$$

S_{b1} , S_{b2} — the frontal area toward liquid of tag 1 and tag 2;

S_R — projection area of tag ball;

S_s — the shaded area of figure 3.

Connect equation (4), (5), (6), simplified as:

$$\pi - 2\alpha + 2 \sin \alpha \cos \alpha = \pi \frac{\mu \cos \alpha - \sin \alpha}{\mu \cos \alpha + \sin \alpha} \quad (7)$$

The following equation can be obtained from the tangential relationship of two tags in figure 3:

$$\frac{4R - D}{2} = R - R \sin \alpha$$

Simplified as:

$$\sin \alpha = \frac{D}{2R} - 1, \frac{D}{4} \leq R \leq \frac{D}{2} \quad (8)$$

In conclusion, study the migration of RFID tag carried by fracturing fluid in tubing with a diameter of 76mm, the extremum of radius of tag has the follow relationship for avoiding tag been blocked with each other in the process of fracturing fluid backflow:

$$\left. \begin{aligned} \pi - 2\alpha + 2 \sin \alpha \cos \alpha &= \pi \frac{\mu \cos \alpha - \sin \alpha}{\mu \cos \alpha + \sin \alpha} \\ \sin \alpha &= \frac{38}{R} - 1 \end{aligned} \right\} \quad (19 \leq R \leq 38) \quad (9)$$

3.2 Equation Solution and analysis

Equation (9) in section 2.1 is a nonlinear equation, the numeric calculation can be obtained by newton iterative method, the solving codes write in MATLAB are showing as following (the friction coefficient was set as 0.1 considering the action of mud and fracturing fluid, the packing material for RFID tag is synthetic resin):

```
%implicit function - show
clear
syms u r %variable
yf=3.1415*u*sqrt(76/r-144/r^2)+3.1415*(38/r-1)-2*u*sqrt(76/r-144/r^2)+2*asin(38/r-1)*(38/r-1)+u*(38/r-1)*sqrt(76/r-144/r^2)^2+(38/r-1)^2*sqrt(76/r-144/r^2)-3.1415*sqrt(76/r-144/r^2)+3.1415*(38/r-1);
ut=0.1; %friction coefficient
f=subs(yf,u,ut);
r0=23; %the estimated initial value for solving numerical solution
```

```
df=diff(f,r);
CF=f/df;
C0=subs(CF,r,r0);
rk=double(r0-C0);
e=abs(r0-rk);
while e>1e-4 %precision
    CK=subs(CF,r,rk);
    rk1=double(rk-CK);
    rk=rk1;
    e=abs(rk1-rk);
end
R=rk %result
```

The calculation result is 23.9465, so blockage can appeared when the radius of spherical tag is around 24mm. The radius magnitude, 23.9465mm, is only one extremum. The suitable range of tag diameter should be $19 \leq R \leq 23.9$ or $24.0 \leq R \leq 38$ that could prevent blocking is discussing in the following:

By force analysis in figure 3 we can learn that, with the radius R reduced, $\sin \alpha$ reduced, $\cos \alpha$ increased, the y components of F_{w1} to tag2 increased, the pressure on the wall of the tubing by tag ball 2 increased. When the velocity of backflow fluid is small, that is the influence on F_{w2} of the change of the frontal area toward liquid of tag 2 is small, obviously the following relationship will appear:

$$F_{w2} + T \sin \alpha < f = \mu(G + T \cos \alpha - F_f) \quad (10)$$

Hence the block situation occurs.

All above analysis of blockage is aimed at two spherical tags, that is the researched radius of tag is $\frac{D}{4} \leq R \leq \frac{D}{2}$.

When the radius of tag ball is less than a quarter of pipe diameter, the situation that two tags blocked with each other can't occur, but in theory the configurations shown as Figure 4 is always occur (only three balls is shown, the rest is similar)

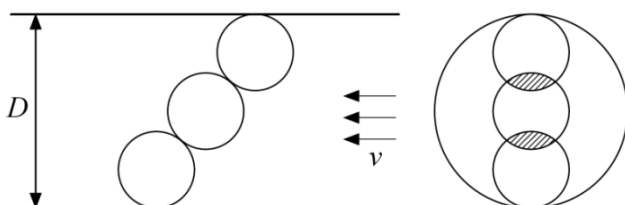


Figure 4: Schematic diagram of three blocking spherical tags

For the smaller diameter, the thrust on tag from fluid is small verified by the simulation analysis above. The configuration of tags is shown as Figure 4, the radial force between

spherical tags lead to the fact that the friction resistance is larger than the thrust, resulting in the blocking. Concrete mechanical analysis and solution is similar with the analysis of two tags researched above.

In conclusion, the diameter of spherical tag selected as 48mm is proper for tubing which diameter is 76mm based on the research of reducing the speed of spherical tag when pass through the smart sleeve and preventing the tags blocked with each other.

4. Conclusion

Smart sleeve staged fracturing tool based on RFID was used in oil formation improvement for reduce fracturing cost. This paper takes the research of diameter selection of spherical tag according to the problem of the lower signal recognition and the backflow blocking. We can get following conclusion:

The larger velocity of spherical tag when passing by sliding sleeve will lead to the lower signal recognition rose in the research background of this paper based on RFID multi stage fracturing technology of horizontal well. Therefore the smaller diameter of RFID tag, the smaller the thrust, the higher recognition of signal within a certain range.

The smaller diameter of spherical tag will lead to blocking in the fracturing fluid backflow process, and the diameter of RFID tag designed for fracturing can optimize with the formula this paper suggested. Through the analysis of spherical tag moving carried by fracturing fluid in the tubing which diameter is 76mm, the diameter of spherical tag select 48mm is suitable.

5. Acknowledgments

This work reported in this paper was supported by the Seeding Program for Technological Innovation of the Science and Technology Department of Sichuan Province (2016128)

References

- [1] Cai X, Tang H, Zhou K. Pattern optimization of hydraulically fractured horizontal wells in low permeability and thin interbedded reservoirs[J]. SPECIAL OIL & GAS RESERVOIRS. 2010, 4(17): 72-74.
- [2] Lohoefer D S, Seale R A, Athans J. New Barnett Shale Horizontal Completion Lowers Cost and Improves Efficiency[J]. SPE 103046. 2006.
- [3] Li S. Research on Technology of Sliding Sleeve Ball Injection Diverter Pipe String in Horizontal Wells[J]. PETROLEUM GEOLOGY & OILFIELD DEVELOPMENT IN DAQING. 2005, 24(4): 67-69.
- [4] Qian X, Deng Y, Liu Y. An Explicit Boundary Level Set Method for Optimization Design of Fluid Channel[J]. China Mechanical Engineering. 2013, 24(15): 2097-2100.

- [5] Li D, Xu C, Xiong Z. Gas flowing model of mining face and solve it using COMSOL[J]. JOURNAL OF CHINA COAL SOCIETY. 2012, 37(6): 967-971.
- [6] Salvi D, Boldor D, Aita G M. COMSOL Multiphysics model for continuous flow microwave heating of liquids[J]. JOURNAL OF FOOD ENGINEERING. 2011, 104(3): 422-429.
- [7] Chen D. Multi-physical field coupling simulation of hygro-thermal deformation of concrete[J]. JOURNAL OF SOUTHEAST UNIVERSITY. 2013, 43(3): 582-587.
- [8] Xu Y, Xu Q. Finite element analysis of seepage based on COMSOL Multiphysics[J]. Engineering Journal of Wuhan University. 2014, 47(2): 165-170.
- [9] Rushd S, Saanders R. APPLICATION OF A CAPACITANCE SENSOR FOR MONITORING WATER LUBRICATED PIPELINE FLOWS[J]. CANADIAN JOURNAL OF CHEMICAL ENGINEERING. 2014, 92(9): 1643-1650.