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# A Study on Drag Reduction Agency for Gas Pipeline

**Zhang Qibin[1], Fan Yunpeng[1,†], Lin Zhu, Zhang Li, Xu Cuizhu, and Han Wenli[1]**

[1]*CNPC Research Institute of Engineering Technology, Tanggu, Tianjin 300451, China*

The drag reduction agency (DRA) for gas pipeline, a novel method used for reducing friction or drag on a gas flowing to increase the transmission efficiency of gas pipeline, is a more flexible and economical technology than internal flow efficient coatings. In this paper, an effective DRA has been developed in Authors' Institute by analyzing the hydrodynamic friction resistance on internal gas pipeline and then studying the work mechanism and molecular structure of DRA. In the meantime, a group of property test for selecting DRA material has been determined, including viscosity, contact angle, volatility, corrosion, slab extending, and flow behavior in horizontal tube. The inhibition efficiency and drag reduction efficiency of the developed DRA have been investigated finally based on the relevant test methods. Results of corrosion test show that the developed DRA has very good inhibition effect on mild steel by brushing a thin layer of DRA on steel specimens, giving inhibition efficiency of 91.2% and 73.1% in 3%NaCl solution and standard salt fog environment respectively. Results of drag-reducing test also show that the Colebrook formula could be used to calculate friction factors on internal pipes with DRA as the Reynolds number is in the range of $0.75\times10^5$~$2.0\times10^5$. By comparing with normal industrial pipes, the friction resistance coefficient of the steel pipe with DRA on internal wall decreases by 13% and the gas flux increases by 7.3% in testing condition with Reynolds number of $2.0\times10^5$.

***Keywords*** *: drag reduction agency, natural gas pipeline, press drop*

## 1. Introduction

Since the construction of West to East Gas Pipeline, the internal flow efficient coating has been used to improve the transmission efficiency for the main gas pipelines in China, such as the SHAN-JING gas pipeline, obtaining significant economic and social profits. Taking West to East Gas Pipeline for an example, the distance between two compressor stations is increased by 16.2%-30%, consequently, three stations were decreased, saving the investment of 700,million RMB. Keeping the same gas output of the pipeline, the operation expenditure of 160 million RMB was reduced every year due to the application of internal flow efficient coating. However, the flow efficient coating has never been used in the pipelines constructed before West to East Gas Pipeline or for the pipeline with small diameter. With the rapid development of exploitation and application of natural gas, the demand grows continually and also changes in different seasons. To meet the increasing demand, enhancing flow pressure of pipeline is a common measure. Sometimes the pressure even outweighs the one designed, which brings danger to the operation of pipeline.

The drag reduction agency (DRA) for nature gas pipeline is a novel method to reduce friction resistance in gas pipeline by forming a lubricous liquid film on internal wall of pipeline. Compared with flow efficient coatings, DRA has some unique characteristics. For examples, DRA can be used in almost all kinds of gas pipeline, especially in small diameter pipeline, while, the flow efficient coatings can only be applied before the construction of pipeline. Furthermore, the expense of DRA is cheaper, and it does not need large investment in one time, because it can be used according to gas demand. So DRA is an economical method, which can not only efficiently increase output of pipeline, but also improve the elasticity of its transportation. Since 1980s, the study of DRA has been carrying out in a few institutions in America and Europe. The research on DRA has made a great progress in the past decades, and in-place experiments were made in year 2000, whose results prove the splendid effect and technical characteristics of DRA. Although DRA has not been used wildly as flow efficient coatings, the desirable economical value and application potential of it are already appeared.

† Corresponding author: ce_fan@hotmail.com

## 2. Technical characteristics and mechanism of DRA

### 2.1 Technical characteristics

Currently, the main method to reduce friction or drag resistance on natural gas flowing is to use internal flow efficient coatings, which is sprayed on the internal wall of pipe, covering the profile of internal wall and reducing friction resistance of gas pipeline. The internal flow efficient coatings require special plants to prefabricate, thus consumes great expense in one time. At the same time, under the limit of spray technology, internal flow efficient coatings can only used in new pipeline with large diameter, but not in existing and small pipelines. Moreover, it is difficult to repair the coating's defects in operation, and the coating broken off accidentally will bring extreme impact on pipeline operation. While, DRA for gas pipeline is completely different from internal flow efficient coatings, having many advantages as follow.

1) When injected into gas pipeline, DRA will adhere onto internal wall, forming liquid film which will not solidify. Therefore, DRA does not require to be prefabricated in plants. It can be applied in-place with suitable apparatuses whenever needed, thus it can markedly decrease the expense in one time.

2) The application of DRA is not limited by pipeline diameter and other factors. DRA can be used in existing pipelines and also the new pipeline projects.

3) The application of DRA is very flexible. It can be injected according to demand of gas flux, and greatly improve the elasticity of pipelines' transportation.

### 2.2 Mechanism of DRA

According to the hydrodynamic principle, flowing behaviors in pipeline can be divided into two categories: laminar flow (Re 〈 2000) and turbulent flow (Re 〉 3000). Turbulent flow comprises three sections: hydrodynamic smooth section, mixed friction section (partly turbulence) and fully turbulence. The gas pipelines generally behave partly turbulence and fully turbulence, but the main gas pipelines almost lie in the third one due to their large diameters, high pressure and rapid flow. In this section, the friction factor λ of pipeline is in accordance with the Equation 1.

$$\lambda = 0.111\left(\frac{K}{D}\right)^{0.25} \text{(K-roughness, D-pipe diameter)} \quad (1)$$

The pressure drop $\triangle P$ along the gas pipeline can be calculated according to Equation 2.

$$\triangle P = \lambda \frac{V^2}{2}\frac{\rho l}{D} \text{(l-length, V-velocity, ρ-density)} \quad (2)$$

Equation 3 can be obtained displacing λ of Equation 2 with Equation 1.

$$\triangle P = m\cdot K^{0.25} \quad m = 0.0555D^{0.75}V^2\rho l \quad (3)$$

According to Equation 3, if V is unchanged, m will be constant because ρ, l, D is constant. Consequently, $\triangle P$ is direct ratio to K.

In horizontal gas pipelines, gas flux can be calculated according to Equation 4.

$$Q = \frac{F}{\rho}\sqrt{\frac{(P_1^2 - P_2^2)D}{\lambda ZRTl}} \quad (4)$$

Keeping other items unchanged, only altering the roughness of pipeline, Equation 5 can be obtained.

$$\frac{Q_2}{Q_1} = \sqrt{\frac{\lambda_1}{\lambda_2}} \quad (5)$$

Displacing λ of Equation 5 with Equation 1, Equation 6 can be obtained.

$$\frac{Q_2}{Q_1} = \left(\frac{k_1}{k_2}\right)^{0.125} \quad (6)$$

From Equation 5, it can be concluded that flux of pipelines can be increased greatly by decreasing its internal roughness.

From above analysis, the main factor that affects the flux and pressure drop in gas pipelines is friction resistance between gas flow and internal wall, and it is direct ratio to pipelines internal roughness. Therefore, the gas flux in pipelines can be increased greatly with the obvious decreases of pressure drop and energy consumption by decreasing its internal roughness.

## 3 Structural traits and property tests

### 3.1 Structural traits of DRA molecule

According to the analysis of DRA's mechanism, materials used for DRA should meet following requirements.

(1) Strong adhesion onto internal wall of pipeline;

(2) Forming stable uniform liquid film;

(3) No volatility and no impact on gas quality.

To meet these requirements, molecule structure of DRA should consist of nonpolar and polar groups. The nonpolar ones which are long carbon chain with suitable molecular weight can form a smooth film between gas flow and pipeline internal wall, decreasing the friction resistance between them and increasing the flux; the polar ones which comprise carbonyl and amido can strongly adhere onto the internal wall, making the film successive and stable.

Based on this analysis and characteristics, several categories of compounds are considered as DRA materials, including alcohol-ethers, esters, amide, imidazoline, and so on, and a series of sample products has been made by proper synthesizing methods.

### 3.2 Analysis of property tests

Considering the conditions where DRA is used and its technical characteristics, a group of property tests is developed to filtrate compounds chosen, which include viscosity, contact angle, volatility, corrosion, slab extending, and flow behavior in horizontal tube.

1) Viscosity--The injection and state of DRA relate closely to its viscosity. DRA with higher viscosity can offer stable film which is lasting and smooth in the gas flow. While, high viscosity also creates difficulties in injecting and extending. On the other hand, lower viscosity makes DRA's injection and extension easier, but it causes the film too thin to cover the roughness and also waves which increase the roughness instead.

2) Contact angle--It is an important item that reflects adhesion between DRA and steel. DRA with smaller contact angle can bind strong on steel and extend easier on it.

3) Volatility--To ensure that DRA have no pollution for natural gas and good aging property, the volatility of DRA should be as least as possible.

4) Slab extending--To forecast the state of DRA film in pipelines, two kinds of experiments were developed, including static slab extending and dynamic slab extending. The first one measures capability of DRA damping steel under no outer force condition. The later gives the results that whether DRA can last longer and overlay roughness of pipeline internal wall.

5) Flow behavior in horizontal tube--Fluid and state of DRA in tube play an essential role in reducing friction resistance. This test was designed to observe Fluid behavior and Waves of the film in horizontal tubes. At the same time, time that waves last and thickness of film can also be measured.

Based on these property analyses, the sample products of potential DRA were tested and evaluated. A best compound material has been determined as DRA, because it has proper viscosity and contact angle, thus can extend well on steel slab, forming successive liquid film. Moreover, it hardly volatilize, that is, can not pollute gas.

## 4. Inhibition effect of the DRA material

Under field conditions, DRA binds onto pipeline internal surface forming a lubricating film of about 50 µm. To test its inhibition effect on mild steel, two kinds of experiments were considered. The procedure used in each

**Table 1. Results of A3 steel hanged in 3% NaCl**

| | blank | | | Sample with DRA | | |
|---|---|---|---|---|---|---|
| number | 1 | 2 | 3 | 4 | 5 | 6 |
| Weight before experiment[g] | 44.2872 | 41.2325 | 42.4526 | 44.1635 | 45.3817 | 38.9892 |
| Weight after experiment[g] | 44.0038 | 40.9527 | 42.1558 | 44.1371 | 45.3569 | 38.9643 |
| change[g] | 0.2834 | 0.2798 | 0.2968 | 0.0264 | 0.0248 | 0.0249 |
| Average change[g] | 0.2867 | | | 0.0254 | | |
| Inhibition[%] | 91.2 | | | | | |

**Table 2. Results of A3 steel hanged in salt fog**

| | blank | | | simple | | |
|---|---|---|---|---|---|---|
| Number | 1' | 2' | 3' | 4' | 5' | 6' |
| Weight before experiment[g] | 44.2529 | 36.0056 | 44.6344 | 43.4133 | 37.5883 | 36.7971 |
| Weight after experiment[g] | 43.3844 | 35.3237 | 43.9177 | 43.2134 | 37.3639 | 36.6118 |
| change[g] | 0.8685 | 0.6819 | 0.7167 | 0.1999 | 0.2244 | 0.1853 |
| Average change[g] | 0.7557 | | | 0.2032 | | |
| Inhibition[%] | 73.1 | | | | | |

test consists of the following steps.

1) Clean the specimens used in tests;
2) Put the specimens into DRA material, soaking for two hours;
3) Draining the DRA and blowing air through the specimens to get rid of excess liquid, the thickness of DRA film is about 50 μm;
4) Put blank and specimens with DRA in different environments for a period of time;
5) Clean and dry all the specimens, weighing up them, calculating the changes in the tests.

Table 1 shows the results of mild steel hanged in 3% NaCl, and Table 2 gives the results of mild steel hanged in standard salt fog environment. Results show that the inhibition efficiencies of DRA are 91.2% in 3%NaCl and 73.1% in salt fog environment respectively.

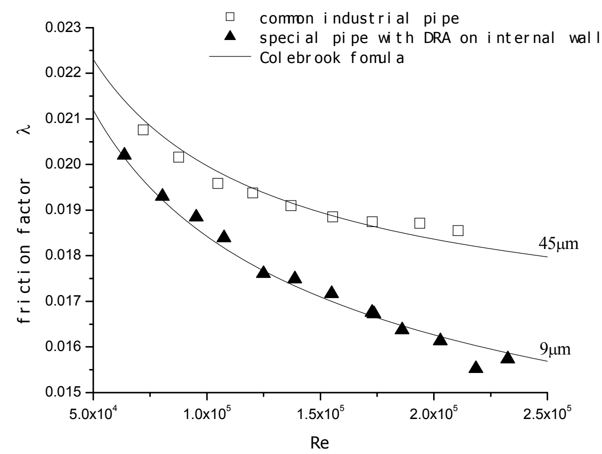


**Fig. 2.** Friction Factors of Special pipe with DRA on internal wall and normal industrial pipe.

## 5. Drag-reducing effect of the DRA material

To evaluate the drag-reducing effect of developed DRA material, simulative gas transmission experiments were conducted on the Drag reduction efficiency of DRA. Two pipes used in the tests include a special pipe with DRA on internal wall and a normal industrial pipe. Fig. 1 gives the sketch map of tests. The first testing hole was arranged at 4.5 m from the inlet end to make sure the length for a fully developed turbulent flow. Six testing holes were arranged along pipe every 5.3 m.

The operating conditions for the tests are as follows:

| | |
|---|---|
| Gas medium: | air |
| Flow rate: | 12m/s -- 35m/s |
| Pipe: | 114×4.5×35000mm |
| Reynolds number: | $0.75\times10^5\sim2.0\times10^5$ |

The procedure used in this test consists of the following steps.

1) Conducting a blank operation in one pipe;
2) Coating the other pipe with DRA, making the DRA an uniform liquid film;
3) Blowing air through the pipes and measuring the pressure at every testing holes;
4) Calculating the friction factor of each pipe.

Fig. 2 gives the results of the friction factors of the special pipe with DRA on internal wall and that of the normal industrial pipe. DRA reduces friction resistance by smoothing the roughness of pipe internal wall. Results of the experiments show that the Colebrook formula could be used to calculate friction factors on internal pipes with DRA as the Reynolds number is in the range of $0.75\times10^5\sim2.0\times10^5$. Drag-reducing effect relates closely to the state of liquid film formed by DRA. If the film is thin and in perfect state, the results calculated with Colebrook formula shows that DRA can decrease the roughness of pipe internal wall to 9 μm. At Reynolds number of $2.0\times10^5$, compared with the normal industrial pipe whose roughness is about 45 μm, friction factor of pipe with DRA is decreased by 13%, and flux increased by 7.3% under the same pressure.


**Fig. 1.** Sketch map of tests

In addition, Fig. 2 also demonstrates that the throughput improvement is flow-condition dependent. Drag-reducing effect at larger Reynolds number is more obvious than that at smaller Reynolds number, so keeping the drag-reduction law no change; it is considered that the Colebrook formula may be also used to extrapolate the test results for the larger Reynolds number.

## 5. Conclusions

(1) The work mechanism and molecular structure of DRA were investigated. A group of property test for selecting DRA material has been designed, including viscosity, contact angle, volatility, corrosion, slab extending, and flow behavior in horizontal tube. An effective DRA material has been developed through synthesizing and properties analyses.

(2) The developed DRA has very good inhibition effect on mild steel by brushing a thin layer of DRA on steel specimens, giving inhibition efficiency of 91.2% and 73.1% in 3%NaCl solution and standard salt fog environ-

ment respectively.

(3) The Colebrook formula could be used to calculate friction factors on internal pipes with DRA for the Reynolds number of $0.75\times10^5$~$2.0\times10^5$. By comparing with normal industrial pipes, the friction resistance coefficient of the steel pipe with DRA on internal wall decreases by 13% and the gas flux increases by 7.3% in testing condition with Reynolds number of $2.0\times10^5$.

## References


1. Proceedings of CNPC Pipeline Technology Conference Corpus, 2004.
2. Huey J. Chen, Gene E. Kouba, Michael S. Fouchi, DRA for Gas Pipelining, Oil & Gas Journal, 2000.
3. Liu Guangwen, Internal Flow Efficient Coatings for Natural Gas Pipeline, p. 11, Petroleum Industry Press, 2001.
4. Robusken, Natural Gas Transport in Pipeline, p. 18, Petroleum Industry Press, 1985.