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Research and Application of Solvent-Free Internal Drag Reducing Epoxy Coating for Non-Corrosive Gas Transmission Service

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Abstract. The developed coating performance meets the corresponding technical specification by using modified epoxy resin and E51 epoxy resin as resin system to optimize the system viscosity and flexibility, adding reactive diluents owning good flexibility, using modified alicyclic amine curing agent with good flexible performance and corrosion resistance, optimizing assistant system concluding defoaming agent, levelling agents and so on. Application adaptability, concluding viscosity, thixotropy, sag resistance and pot life, were also studied under different temperatures, considering that these parameter are important to spraying process. The dry film thickness can be adjusted between 60-150 μ m by modulating spraying application parameters, meanwhile, the flat smooth film meets internal drag reducing coating technical parameters requests. The product were successfully applied in China key projects. According to field pilot test, application attention items were also discussed.

1. Introduction

Epoxy internal drag reducing coating of gas pipeline technology was first applied in the early 1950s in United States. Field tests have shown that the inner coating can significantly reduce pipeline resistance and increase pipeline carrying capacity.¹⁻³ After decades of development applications, the United States and Europe pipeline coating drag reduction technology and construction experience has been relatively mature and a series of standards has been made, such as Recommended Guidelines for Internal Coating of Pipelines established by American Petroleum Institute and CM1 and CM2 standards created of England.⁴ In China, internal drag reducing coating was first applied in West-East Gas transmission project. At the early stage of the project, the internal drag reducing coating adopted were mainly imported from abroad such as COPON BP2306HF of E. Wood Ltd and Permacor 337 from Germany. The industrial examination of AW-01 coating developed by China petroleum group engineering institute of technology was carried out between DaGang-CangZhou 406 gas-transferring pipeline in 2001 and the result showed that the increased value of pipeline flow data is 20.9% which means that the performance has reached international level. AW-01 coating was applied in the west -to -east gas pipeline project in 2003, afterwards, the coating was widely used in Shaanxi-



Beijing Gas Pipeline II, West-East Gas Pipeline II, Sichuan to East Gas Pipeline Project and other large long distance natural gas pipeline. In these actual engineering, AW-01 coating showed good performance and obtained good results.⁵

Up to now, considering that solvent-free coating owns many merits comparing with solvent coating such as don't contain organic solvents, don't pollute environment, be harmless to humans, be safe, and avoid wasting a lot of organic solvents, the solvent-free internal drag reducing coating development has become the major trend.⁶ Furthermore, solvent-free internal drag reducing coating owns better performance of abrasion resistance, anti-shearing, resistance to chemical media soaking performance.⁷ E. Wood Ltd and Bredero Shaw Ltd has developed solvent-free epoxy internal drag reducing coating and the coating has been applied in industry. As for its China's domestic application, up to now, according to the available information, solvent-free epoxy internal drag reducing coating industrial began to be widely used in 2017.

In this study, the development ideas of the coating were discussed and application adaptability were studied. Meanwhile, not only the coating film is flat and smooth, but also it owns high gloss and low roughness, which is significant for the internal drag reducing coating.

2. EXPERIMENTAL PROCEDURE

2.1. Material

Modified epoxy resin, E-51 epoxy resin, Modified polyamide curing agent, Pigments and Fillers, Anti-settling thixotropic agent, Defoaming agent, Dispersing agent.

2.2. Preparation of the coating

Stir the epoxy resin and additives evenly, then add pigments and fillers in the dispersing tank. Disperse the mixture in dispersion machine at the speed of around 2300r/min. During the dispersing process, keep the mixture temperature within the range of 50°C to 60°C for 30min to activate the polyamide wax class which functions as thixotropic agent. Afterward, grinding the mixture at decent pace to meet the fineness requirement which is lower than 50µm.

2.3. Preparation of test samples

Blend the configured A and B component in proportion. Prepare test samples according to corresponding international standards.⁸

3. RESULTS

3.1. Research approach

The difficulties of developing solvent-free internal drag reducing epoxy coating for non-corrosive gas transmission service include the following points, high solid content, excellent bending resistance, low viscosity to guarantee good application adaptability, excellent corrosion resistance. Traditional solvent based coating development methods were no longer applicable. Therefore, modified epoxy resin, E-51 epoxy and AGE reactive diluents were used as film-forming resin to endow coating system low viscosity and excellent bending resistance. Modified 100% solid content alicyclic amine curing agent with about 1000mPa·S viscosity was used as curing agent to guarantee excellent corrosion resistance and bending resistance. Moreover, the system of filler, auxiliary system and thixotropic agent were further optimized to improve the system comprehensive properties. The coating property inspection results were shown in Table1 accordingly.

Table 1. Coating property inspection results

Test item		Performance		Test methods
		API RP5L2	Test coating	
Pinhole test	Wet film	No pinhole	Attained	API RP 5L2 Appendix G
	Dry film	No pinhole	Attained	API RP 5L2 Appendix G
Gas Blistering		No Blistering	Attained	API RP 5L2 Appendix E
Hydraulic Blistering		No Blistering	Attained	API RP 5L2 Appendix F
Abrasion		30.0	Attained	ASTM D968-05(2010)Method A
Hardness(Buchholz)25±1°C		113	Attained	ISO 2815-2003(E)
Adhesive force		No any peeling except for at the site of cut	Attained	API RP 5L2 Appendix D
Bending test		Bending cylinder of 13 mm diameter , visual inspection, No peeling or cracking	Attained	ASTMD522
Peeling test		The coating should not be scraped in strips, but should be peeled in sheet. When twisted , the peeled sheet should be powder particles	Attained	API RP 5L2 Appendix C
Water soaking		No blisters within 6.3 mm from the sample edge	Attained	Saturated solution of calcium carbonate, 100% soaking , room temperature, 21d
1:1 volume of water and methanol mixture soaking test		No blisters within 6.3 mm from the sample edge	Attained	100% soaking, room temperature, 5d
Salt Spray(500h)		The coating exhibits no blistering,and 2.4mm of coating removed.	Attained	API RP 5L2 Appendix B
Adhesion (Pull-off test),MPa		18.6	Attained	ASTM D4541-09e1
Shear Strength,MPa		18.2	Attained	ASTM D1002-2010

3.2. Coating viscosity

Generally, considering that solvent-free coating owns high viscosity and needs high spray pressure, it is usually to form leakage point when for getting thin film, therefore, preventing the viscosity of solvent-free coating too large is one of the important adjustment directions. In formula design, it is necessary to add thixotropic anti-settling agent which also owns certain thickening effect to endow the coating certain thixotropic property.

High-pressure airless spraying technology was adopted to carry out spraying process. If the viscosity difference between A and B component is too huge, it would affect the atomization effect or cannot be used by spraying method. Therefore, it is advantageous to conduct spraying construction when placing part of the fillers in component B which can reduce a component viscosity.

Component viscosity at different temperature was shown in Table 2. From the data of table 2, we can conclude that the viscosity of every component reduce accordingly along with the increase of temperature. And the viscosity is convenient to conduct spraying construction.

Table 2. Component viscosity at different temperature

Temperature(°C)	Viscosity(mPa·s)		
	A component	B component	A and B mixture
35	3239	8980	5899
40	2799	6898	3799
45	2236	4367	2635
50	1435	3205	2358
55	1136	3885	1935

3.3. Thixotropy and sag resistance of coating

The relationship of sag resistance and leveling performance are opposite. The increasing of coating viscosity is good for sag resistance but adverse to leveling performance while increasing the coating thickness can improve the leveling performance but aggravate the degree of sagging. Endowing the coating appropriate thixotropic performance can obtain good balance between leveling property and sag resistance.⁹ Ideal thixotropic agent, which can improve the application property and does not have negative impact to the film gloss and adhesion performance, requires high thixotropy, anti-settling property, and temperature stability. Comparing with polyamide wax, hydrogenated castor oil is relatively sensitive to temperature, in detail, the thixotropy effect reduced greatly when temperature is above 60°C and can't regain the thixotropy property after the coating cooled down. Combining the internal drag reducing coating construction environment and curing temperature, it is reasonable to choose polyamide wax as thixotropic agent.

Component thixotropy index at different temperature were shown in Table 3. From the data of Table4, we can know that within the range of 35°C-55°C, the thixotropy of both single component decrease accordingly and the thixotropy of A and B mixture fluctuates in small scope as the environment temperature increase.

Table 3. Component thixotropy index at different temperature.

Temperature(°C)	Thixotropy (6rpm/60rpm)		
	A component	B component	A and B mixture
35	1.33	4.93	2.69
40	1.33	4.64	2.36
45	1.32	4.43	2.39
50	1.32	4.32	2.33
55	1.31	4.30	2.30

Coating sag resistance at different temperature were shown in Table 4. From Table4, we can know that coating sag resistance decreased accordingly as the temperature increased within the range of 35°C-55°C, which means that the maximum dry film thickness decreased accordingly. The results showed that the dry film thickness can reach 150µm at 55°C, which meets the requirement of inner drag reducing coating film thickness.

Table 4. Coating sag resistance at different temperature

Temperature(°C)	Maximum dry film thickness /µm
35	180
40	170
45	165
50	155
55	150

3.4. Coating pot life

Pot life, one important parameter in coating construction process, is also known as usable time and working life, which means that the period of time after mixing during which two mutually reactive component remain usable. When testing the pot life, it was the period during which the viscosity of 250g samples increased by 100% comparing with the original viscosity. Coating pot life at different temperature were shown in Table 5. From Table 5, we can know that the coating pot life reduced accordingly as the environment temperature increased within the range of 35°C to 55°C.

Table 5. Coating pot life at different temperature

Temperature(°C)	Pot Life/min
35	60
40	55
45	40
50	35
55	30

3.5. Engineering applications

The developed product was widely applied in the actual project. Two-component high-pressure airless spraying machine was adopted to carry out the spray test. Two metering pump work at the same time and deliver A and B component through two independent pipelines accordingly. A and B component were blended in the mixer and then were conveyed to airbrush to carry out spraying construction. Generally, the closer of volume usage of two components, the more convenient for the equipment to execute construction. When the usage volume difference of two components is small, on the one hand, the work frequency of two pumps would be close, which would reduce the equipment damage probability; on the other hand, the mixing efficiency of two components would increase, by which the film would cure more evenly and the usage deviation would decrease.

The on-site spraying construction and field test photos were shown in Fig1-Fig 2. The spraying parameters were shown in Table 6- Table 7 accordingly. Generally, the field spray achieved good results, and we accumulated certain construction parameters and valuable application experience.



Figure 1. Pipeline of after spraying solvent-free epoxy internal drag reducing coating



Figure 2. Test record of dry film thickness and roughness

Table 6. Representative Spraying parameters

Spraying pressure	0.5MPa
Spraying pressure ratio	56:1
Nozzle specifications	163-921 of Graco Inc.
Steel pipe specification	Φ1219 cm
Airbrush moving speed	26-35 cm/s
Coating temperature when spraying	40°C
Filter gauze	Filter gauze at the pump:200 mesh Filter gauze at the pump:200 mesh
Temperature of curing oven	45°C

Table 7. Online inspection results of spraying test

Item	Spraying velocity (Airbrush moving speed, cm/s)	Thickness of wet film(μm)	Thickness of dry film(μm)	Roughness (μm)	Gloss (Gs)
No. 1 steel pipe	26	130-160	125-150	1.2-2.0	98
No. 2 steel pipe	28	120-150	115-130	2.5-3.1	95
No. 3 steel pipe	33	110-140	100-120	1.9-3.0	96
No. 4 steel pipe	35	90-110	80-100	2.9-3.6	95
No. 5 steel pipe	37	80-100	60-90	3.0-3.8	93

4. Conclusion

The developed coating performance meets the corresponding technical specification and the coating owns excellent application adaptability. As for the coating application and construction process, there are some items needed to pay attention.

1. The appropriate construction viscosity is very important for the spraying construction. It is likely to produce the screw and pinhole when the viscosity is too large, while it is likely to sag when the viscosity is too small. Considering that appropriate construction viscosity differs under different temperatures, it is necessary to explore the coordination among the environment temperature, spraying equipment and the construction viscosity.

2. Generally, in order to ensure the coating good service performance, it is better to guarantee the coating temperature between 40°C to 55 °C by taking temperature control measurements, otherwise, it is likely to produce the screw and pinhole and affect atomization effect which would lead to the appearance deterioration when the temperature is too low. When the temperature is too high, the pot life would be shortened and it is bad for the spraying construction.

3. Considering that the pot life shortened comparing with the solvent inner drag reducing coating, the mixture of A and B component is suggested not to stay in the mixer for a long time to prevent blocking pipe because of curing reaction.

4. It is suggested to preheat the steel pipes to prevent the defect of pinhole and wrinkles caused by the wide temperature difference between coating and steel pipe.

5. Considering that the fineness request for the inner drag reducing coating is less than 50µm, it is suggested to use 200 mesh and 100 mesh filter gauze at the pump and airbrush to guarantee the film performance. The abrasion level to the nozzle is usually high because of adding part of hard abrasive resistant fillers in the formula, to guarantee the spraying quality, it is suggested to renew the nozzle periodically.

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