CO_2 compressor corrosion and scaling problems

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Introduction

In June 1992 Petrochina Ningxia Petrochemical Company's second largest ammonia/urea plant was purchased from Canada as second-hand equipment. Originally the plant was put in operation in November 1967, the design capacity of the ammonia plant is 1000 stpd (907 mtpd), the CO_2 desorption process is using sulfolane solution as agent. The major equipment including the CO_2 compressor were purchased from Mexico, where it was many years idle. The original design capacity is 1500 mtpd of urea.

In 1997, it was decided to revamp the ammonia and urea plant in order to reach a production capacity of 1000 mtpd ammonia and 1740 mtpd urea. Regarding the CO_2 compressor section the main measures taken was to increase the suction pressure from 0.08 MPa to 0.10 MPa. In the meantime the CO_2 washing section in ammonia plant will use aMDEA solution. In September 1999, the plants were put into operation and after one year of operation the new design production capacities were realized.

In 2004, in order to meet the strong market demand for urea product, Ningxia Petrochemical Company decided to implement another revamp and to increase the output of the plant with 50% in order to realize 1500 mtpd ammonia and 2610 mtpd urea.

The revamp work on the CO_2 compressor was performed by the original manufacturer Nuovo Pignone. A booster compressor (including the droplet separator) was installed to increase the inlet pressure and mass flow; and the high and low pressure compressor internals were revamped. The unit auxiliary facilities such as coolers and separators did not need any changes.

1. Description of the problems

Several instances after starting up the plant after the first revamp erosion damages occurred on the carbon dioxide compressor rotor and the flow channel (mainly low-pressure cylinder). Further normal operation was seriously affected by scaling leading to frequent shut downs of the complete plant after 8 to 12 months.
In the summer of 2003 the inspectors found serious damage of the low-pressure cylinder rotor and cylinder flow channel. In the flow passage a lot of dirt accumulated. Repair was performed by spraying the surface with a layer of stainless steel 7Cr13, coating thickness is between 0.3 ~ 0.5mm. Meanwhile, in order to reverse this situation, Ningxia Petrochemical Company installed an ammonia cooler (surface 195 m^2) downstream the CO_2 desorption column separator. Further in CO_2 compressor section they added a separator in series with the original one, in order to maximize the removal of entrained water from the CO_2 gas. By these measures the CO_2 compressor operating conditions improved compared with before.

In 2005, Ningxia Petrochemical Company implemented the second revamp project including the CO_2 compressor system improvements. These consist mainly of adding the booster compressor and at the

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suction side of the booster the additional cooler and separator and finallt the replacement of demister wire mesh of stainless steel in the original CO_2 compressor section.
Meanwhile, the company commissioned the new Nuovo Pignone compressor internal parts (rotor and the flow channel) to accommodate the revamp requirements.

During the maintenance turnaround of 15-30 July 2007, Ningxia Petrochemical Company found a large amount of catalyst dust in 102E (carbon dioxide stripping tower), 109C (102E bottom heat exchanger), 107J (MDEA solution pump), 105CA/CB (102E reboiler), 102F (condensate splitter transformation), J66401 (transformation process condensate pump) and other equipment and of some heat exchangers, such as 105CA/CB, most of the tubes were completely blocked.

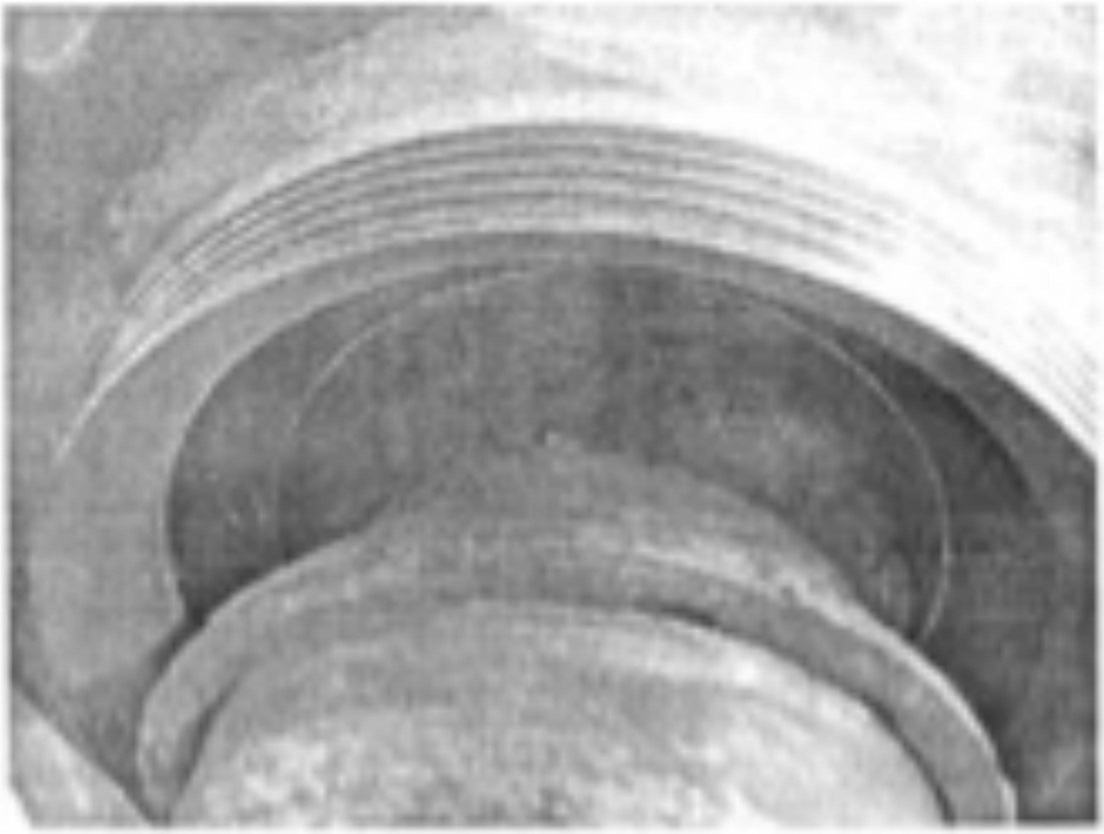

图 1 宁夏石化公司 CO_2 压缩机组
三段入口流道损伤图片

In September 2007 during the CO_2 compressor inspection, they found at three sections of high-pressure cylinder that the rotor entrance flow channel were severely eroded (see Figure 1), and they were forced to sent these to compressor manufacturing company Shenyang Blower to carry out the necessary repairs.

In addition, Ningxia Petrochemical Company replaced about 30m length of the pipe from the CO_2 desorption tower to the booster from carbon steel pipe material to stainless steel and improved the insulation in order to reduce the corrosion of carbon steel pipe products. But about 70m before the separator the piping material is still of carbon steel.

As the ammonia cooler experienced tube leakage problems, it could not realize the expected results.

Thus, while Ningxia Petrochemical Company had implemented several preventive measures for improving the reliability of the CO_2 compressor unit it still failed to fundamentally solve the problem.

2. Related technical information

2.1 CO_2 Compressor design parameters before and after transformation

Table 1.

表 1 CO_2 压缩机改造前后的设计参数

CO_2 压缩机	机组原设计参数	改造后要求达到的参数
标态流量/$Nm^3 \cdot h^{-1}$(干)	24 750	正常 45 130/额定 47 390
进口压力/MPa(G)	0.08	0.11
进口温度/℃	45	45
出口压力/MPa(G)	153	153
出口温度/℃	121	~121
轴功率/kW	7 645	11 500
转速/$r \cdot min^{-1}$	6 935/13 305	7 098/13 636

2.2 Ningxia Petrochemical Company CO_2 replacement of the material before and after the compressor

Transformation of the previous material in table 2 and new material in table 3.

表 2 改造以前的材质

项目	气缸	轴	叶轮	隔板
低压缸	ASTM A216WCA	40NiCrMo7	F.W+12Cr13	铸钢
高压缸	ASTM A105/11	40NiCrMo7	X12Cr13	X12Cr13

改造以后的材质见表 3。

表 3 改造以后的材质

项目	气缸	轴	叶轮	隔板
低压缸	ASTM350 LC2 铸钢+真空表面不锈钢 AISI316	40NiCrMo7	一级和四级为 ASTM A705/630,其余为 ASTM A240(相当于 X12Cr13)	ASTM A266
高压缸	ASTM A743 CA15 + ASTM A240(相当于 X12Cr13)	40NiCrMo7	一级和四级为 ASTM A705/630,其余为 ASTM A240(相当于 X12Cr13)	ASTM A266

2.3 CO_2 comparison with similar plants

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Desorption tower technical conditions for the export separator comparison
Table 4.

表 4　与同类装置 CO_2 解吸塔出口分离器技术条件对比

项目	宁夏石化	某甲公司		某乙公司
数量	1	2		1
位号	103F	1103F	1103FA	103F
直径/mm	2 591	2 747	2 622	3 000
高度/mm	6 655	9 193	11 200	10 131
容积/m³	31.6	50.0	57.0	64.5
总容积/m³	31.6	107.0		64.5
结构	出口丝网除沫器厚度为 200 mm	出口丝网除沫器厚度为 200 mm	出口丝网除沫器厚度为 200 mm	出口丝网除沫器厚度为 200 mm

2.4 CO_2 comparison with similar plants

Compressor auxiliary equipment (coolers and separators). Technical conditions for comparison

Table 5.

表 5　与同类装置 CO_2 压缩机附属设备(冷却器和分离器)技术条件对比

项目		宁夏石化	某甲公司	宁夏与某甲公司相比	某乙公司	宁夏与某乙公司相比
压缩机组冷却器面积/m²	人口	320(不包括氨冷器面积 195)	559	57.25%(包含氨冷器时为 92.13%)	727	44.02%(包含氨冷器时为 70.84%)
	一段	350	588	59.52%	503	69.58%
	二段	157	307	51.14%	277	56.68%
	三段	110	237	46.41%	254	43.31%
增压机入口分离器容积/m³		10.60	18.84	56.26%	无增压机	—
压缩机组分离器容积/m³	人口	28.00	37.00	75.68%	27.80	100.72%
	一段	8.344(2 个串联,容积分别为 5.33 和 3.014)	23.06	36.14%	9.40	88.77%
	二段	1.94	7.83	24.78%	3.50	55.43%
	三段	0.93	3.96	23.48%	2.30	40.43%

2.5 CO_2 Compressor fouling element analysis results

Table 6.

表6 CO_2压缩机内件垢样成分分析结果

样品成分	含量/%
总铁	60.15
Al_2O_3	6.97
SiO_2	11.75

iron 60.15 wt%

3. Analysis

Ningxia Petrochemical Company's second largest fertilizer plant CO_2 compressor several times suffered with fouling and erosion damages of the inner parts (the rotor and the partition). We did do an thorough investigation through on-site investigation and related data files and technical literature, as well as through analysis and tests and visits to similar ammonia and urea plants. This has been a serious long-term trouble for Ningxia Petrochemical Company and the cause and solutions of the CO_2 compressor scaling and erosion problems should be analysed and derived thoroughly from its fundamentals. Based on a broad analysis of literature and references, we believe that Ningxia Petrochemical Company CO_2 compressor mechanical erosion damage and fouling phenomena were caused mainly by the following reasons:

3.1 The separation of water from the CO_2 gas is insufficient

At Ningxia Petrochemical Company the CO_2 gas only flows through a separator before entering the CO_2 compressor of the urea plant. The separation of water has not been efficient enough. Reference A plant has two separators and an ammonia cooler at the suction side of the CO_2 compressor leading to a better separation of water.
From the data in the previous table we can also see that reference A's CO_2 desorption tower has two separators, which are bigger than the separator at Ningxia Petrochemical Company, for example the total volume compared to Ningxia Petrochemical Company is more than three times; Reference B plant has only one separator, but the volume compared to Ningxia Petrochemical Company is two times larger. As the Ningxia Petrochemical Company separator diameter, height, volume and other technical parameters are less than the references, the gas flow through the separator is relatively high leading to more entrainment of water droplets.

3.2 Cooler area and the volume of the separator is too small

Comparing the data from the previous tables we can see that the bad operating conditions of the ammonia cooler cannot be due to tube leakage but is also caused by a too low heat exchange area as it is two-third than that of the reference plants.
Although Ningxia Petrochemical Company added a new separator the total volume is only about one third of the reference A plant. When comparing with reference B plant the total volume is similar but because two separators in series, each with a relative small diameter, the flow of CO_2 gas through the separators is relatively high and entrainment of droplets becomes likely. As the ammonia cooler heat exchange area is too small, insufficient cooling of gas occurs and coupled with the relatively small separator volume, it is difficult to accomplish a complete separation of CO_2 gas and water.
The tiny water droplets and the larger CO_2 flows created a water hammer effect at the entrance of the compressor and caused severe mechanical erosion damage of the flow channel.

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3.3 Ammonia conversion and shift conversion catalyst and the CO_2 desorption tower entrainment cause corrosion of the carbon steel pipes and related equipment and scaling inside the compressors parts (rotor and the partition)

Physical and chemical analysis was performed of the scaling of the CO_2 compressor and it was found that the main ingredient is iron. The iron should origin mainly from corrosion of the carbon steel pipes and equipment of the CO_2 line from the ammonia plant desorption tower (102E) and from the high-temperature shift catalyst. The remaining ingredients of the scales are Al_2O_3 and SiO_2. It was speculated that these substances may come from dust from the converter and shift catalyst. According to the relevant materials, the conversion component of the catalyst is nickel oxide, the active ingredient is nickel, the carrier is a phosphate diatomaceous earth (the main component is a kaolin and SiO_2; The high temperature shift catalyst used is iron-based catalyst, the low temperature shift catalysts used are copper and its carrier is Al_2O_3.
Because Fe_2O_3, Al_2O_3, SiO_2 have a certain solubility in water (although SiO_2 has a very low solubility), these substances are encountered in the decarbonization section and dissolved in the MDEA solution (desalination water content of about 50% or so), and finally then with the CO_2 gas in the water going into the compressor. Together with the bad separation of water in the separators at Ningxia Petrochemical Company, resulting in droplets containing the above substances (or the saturated water) into the compressor. When the CO_2 gas is compressed the process temperature rapidly increases (100 ℃ above) and moisture goes from the liquid into a gaseous state, while the dissolved material will gradually accumulate in the compressor and get attached to the surface of several parts.

3.4 Unit revamp: lack of careful consideration leaving the hidden dangers

At reference A and B's CO_2 compressor revamp, the Design Institute also revamped the relevant subsidiary equipment like coolers and separators to meet the operating conditions after revamp; At Ningxia Petrochemical Company only the demister in the separators were replaced, leading to difficulties to ensure a reliable operation.
Moreover reference A and B's urea plant production capacity increase was only up to 2300 mtpd and Ningxia Petrochemical Company's production capacity has been increased to 2610 mtpd.
Furthermore reference A has two separators and a cooler installed upstream the compressor realizing a relatively good separation. While at Ningxia Petrochemical Company also added a cooler but this one suffered many times from tube leakages, so could not function properly.
The revamp increased the design capacity increased by 50% and thus also the CO_2 compressor load increased by 50%. At Ningxia Petrochemical Company the compressor internals were revamped, but not the subsidiary equipment (coolers and separators). This approach is undoubtedly the reason for many potential problems hampering a safe and reliable operation.
In addition, Ningxia Petrochemical Company second largest fertilizer plant the actual capacity reached only 85% after the revamp, due to a bottleneck in the ammonia synthesis gas compressor unit (103J).
At two similar devices the CO_2 compressors were studied. These compressors run for long periods of time at full load (design capacity) and stable operation, but there has not been found any significant damage or scaling of inner part

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4. Conclusions

During two test periods Ningxia Petrochemical Company fertilizer plant CO2 compressor showed shaft seal leakages indicating that the CO_2 gas contains too much water, contributing to CO_2 compressor erosion damages. After catalyst dust caused fouling in the compressor, we examined if these phenomena in similar devices had happened. To solve the Ningxia Petrochemical Company CO_2 compressor erosion damage and scaling issues, the cooler and the volume of separators should be increased in size to prevent the ammonia plant converter and shift catalyst dust entering the compressor. Also effective measures were take to reduce the formation of corrosion products from the equipment and piping of the CO_2 washing section in the ammonia plant.

Translator notes:
This is a Technical Paper originating from www.Ureanet.cn. The paper was original in Chinese language and it is translated and interpreted into English with care and as much as reasonable possible accuracy, all to the best of our abilities