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# Analysis of Performance Deviation for the Circulating Hydrogen Compressors of Reforming Unit

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***Abstract:*** Catalytic reforming is one of the important secondary processing methods in the refining process. It uses naphtha as raw material to produce high-octane gasoline components and organic chemical raw materials, and at the same time, cheap hydrogen is produced as a by-product. The circulating hydrogen compressor unit is the "heart" of the continuous reforming unit, and it is the power source for delivering the hydrogen produced by the reforming system to the downstream hydrogen consuming units. This paper takes the Circulating hydrogen and hydrogen booster compressors in Reforming Unit as the research object, aiming at the performance deviation phenomenon of the compressor during the operation process, and analyses the root cause of the deviation. After investigating through the comparative analysis of designed parameters and operating data, performance curve comparison, and medium composition, the key influencing factors causing the deviation are determined and further confirmed through third-party testing. This study provides a correct method for testing the molecular weight of circulating hydrogen compressors, and has an important guiding role for the performance evaluation of the same type of compressor units.

## 1. Introduction

The reforming circulating hydrogen compressor and the hydrogen booster compressor are important dynamic equipment in the continuous refining reformer. The circulating hydrogen compressor provides circulating hydrogen to the reactor, and the hydrogen booster is responsible for sending the excess hydrogen out of the device. The two devices have two different process arrangements, namely parallel and serial [1]. In the serial arrangement, the inlet pressure, temperature, and medium conditions of the two compressors are the same.

The performance of the compressor affects the operation of the entire reformer. Users and compressor manufacturers attach great importance to how to ensure stable compressor performance, reduce performance deviation, improve the control accuracy of the compressor system, and there are many related research results. For example, Zhang Jianxin studied the fluctuation of parameters such as the inlet flow rate of the circulating hydrogen compressor [2, 3], Wang Yingbo studied the surge problem of the reforming circulating hydrogen compressor [4], and Chen Long studied the problem that the anti-surge valve of the circulating hydrogen compressor cannot be automatically closed [5]. However, the problem of incorrect calculation of compressor performance due to the relatively large deviation of the molecular weight of the medium has not attracted widespread attention.

In this paper, we target the large deviation between the performance of the reforming Circulating hydrogen compressor and that of the hydrogen booster compressor during the operation of China Petroleum & Chemical Corporation Luoyang Branch's 2# continuous reforming unit. We then carry out a problem investigation and analysis of the cause and confirmed the influencing factor of the performance judgment of the compressor.

## 2. Performance Deviation

The Circulating hydrogen compressor (C201) and hydrogen booster compressor (C202) of China Petroleum & Chemical Corporation Luoyang Branch's 2# continuous reforming unit are both centrifugal barrel compressors. The model of the Circulating hydrogen compressor is BCL708, and that of the hydrogen booster compressor is BCL709+BCL709+BCL709. The two compressors are in parallel arrangement, and their main design parameters are shown in Table 1. More than 85% of the medium is $H_2$, with the rest is being $C_1$-$C_{10}$ alkane components. Since different oil are used in different operating phases, the molecular weight of the compression medium varies between 6-9.

After the unit is running, the operating data of the two units monitored by the user are shown in Table 2. According to the comparison of design and operating data, the operating values of the two compressors have the following characteristics:

1) The measured molecular weight of the compressor is 11% smaller than the minimum molecular weight of the design condition.

2) The operating rotating speed of the compressor is only 85%-82% of the design speed.

3) The weight flow of the compressor is much larger than the design value.

Table 1: Compressor design value.

| | Circulating hydrogen compressor | | booster compressor | |
|---|---|---|---|---|
| | design value | | design value | |
| case | Normal 1 | Normal 2 | Normal 1 | Normal 2 |
| Weight flow/ $Nm^3/h$ | 78777 | 104433 | 80545 | 77897 |
| Molecular weight | 7.22 | 9.01 | 6.87 | 8.56 |
| Inlet Temperature/℃ | 40 | 40 | 40 | 40 |
| Inlet Pressure/barA | 3.5 | 3.5 | 3.5 | 3.5 |
| Outlet Pressure/barA | 6.5 | 6.5 | 29 | 29 |
| Outlet Temperature/℃ | 97.01 | 108.68 | | |
| Pressure Ratio | 1.857 | 1.857 | 8.286 | 8.286 |
| Volume flow/ $m^3/h$ | 26829 | 35332 | 27418 | 26527 |
| Speed r/min | 6675 | 7188 | 7173 | 6490 |

Table 2: Comparison of compressor design value and operating value.

| | Circulating hydrogen compressor | | booster compressor | |
|---|---|---|---|---|
| case | design normal 1 | operating value | design normal1 | operating value |
| Weight flow/ $Nm^3/h$ | 78777 | 104270 | 80545 | 93715 |
| Inlet pressure Mpa | 0.35 | 0.3495 | 0.35 | 0.35 |
| Inlet Temperature/℃ | 40 | 37.08 | 40 | 36.4 |
| Outlet Pressure/barA | 0.65 | 0.6035 | 2.9 | 2.668 |
| Outlet Temperature/℃ | 97.01 | 91 | 107 | 108.2 |
| Molecular weight | 7.22 | 6.39 | 6.87 | 6.39 |
| Pressure Ratio | 1.857 | 1.724 | 8.286 | 7.623 |
| Volume flow/ $m^3/h$ | 6675 | 5656 | 7173 | 5884 |

From the comparison above, it can be preliminarily concluded that the compressor inlet pressure and temperature are close to the design value, but the molecular weight is smaller than the design value. It is very strange that when the rotational speed is much lower than the design value, the compressor pressure ratio is close to the design value, and the mass flow rate has increased a lot. When the user wants to reduce the compressor flow by reducing the speed, the speed approaches the lower speed limit of the steam turbine. The user believes that the two compressor units are designed to be too large, which has led to the high energy consumption of the units.

## 3. Troubleshooting the Cause of Performance Deviation

### 3.1. Data Accounting

Assuming that all on-site test data are accurate, the compressor manufacturer accounted the relevant performance data of the compressor, and the results of the reformed compressor are shown in Table 3.

Table 3: Comparison of compressor design value and operating value.

| performance parameter | Unit | design normal 1 | operating value |
|---|---|---|---|
| Impeller peripheral speed u2 | m/s | 244.528 | 207.198 |
| Inlet enthalpy | kJ/kg | 192.7 | 193.02 |
| Outlet enthalpy | kJ/kg | 479.8 | 483.55 |
| Enthalpy difference between inlet and outlet | kJ/kg | 287.1 | 290.54 |
| Average head coefficient per impeller stage | | 0.6 | 0.85 |
| Inlet volume flow | $m^3/h$ | 26829 | 34362 |

According to the high performance of the unit and the calculation value in Table 3, the core performance data of the reforming compressor are corrected to different degrees. The comparison results of the simulation are shown in Figure 1.

In Figure 1, curve 1 represents the “flow - pressure ratio” curve obtained from the data from the core in the original design under the condition of molecular weight 6.39 and n=5656. Both the flow rate and the pressure ratio are much smaller than the operating value.

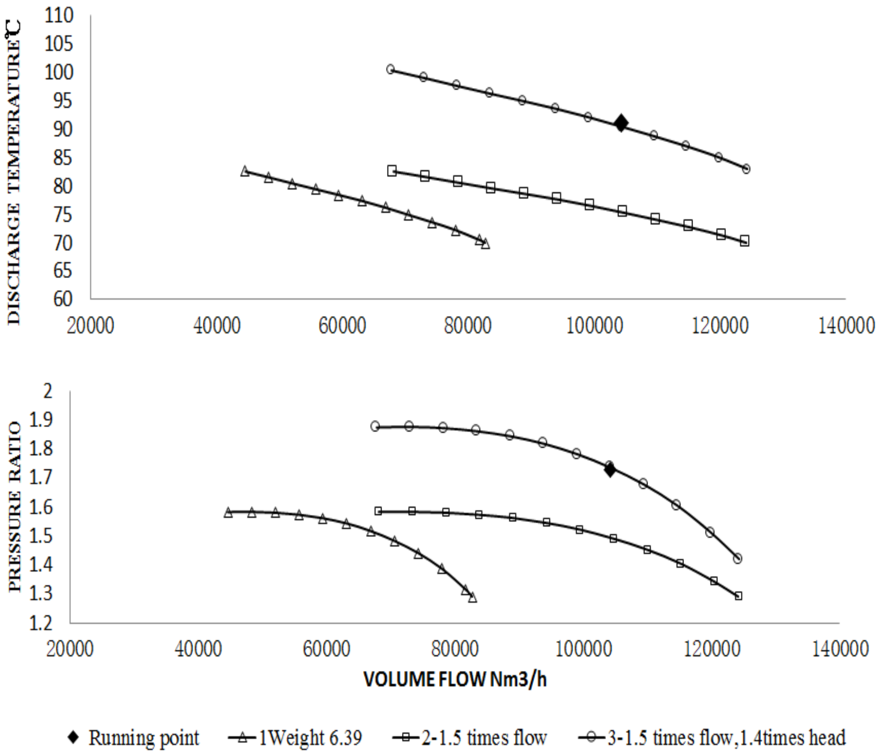


Figure 1: Simulation curve assuming the compressor is too large.

In order to simulate the on-site situation, according to the data in Table 3, the flow coefficient of the compressor impeller is artificially increased by 50%. As shown in curve 2, the flow rate can reach the operating point at this time, but the pressure ratio is not enough, indicating that the function of the impeller is insufficient and that the energy head still needs to be increased.

In addition to increasing the flow rate by 50% in curve 2, continue to increase the energy head by 40% to obtain curve 3. At this time, the pressure ratio and outlet temperature are consistent with the operating point.

Assuming the simulations above are true, the compressor impeller has an average head coefficient of 0.85 at the operating point, a 42% increase over the design value.

### 3.2. Compressor Aerodynamic Design Method

The aerodynamic design method of the reforming Circulating hydrogen compressor follows the "Similar Modelling method of the centrifugal compressor" [6]. All the impellers used passed the performance test are applied in the product according to the scaling ratio of 1.4.

The basic principle of the "Similar Modelling method" is that when the application of enlargement follows the measurement, and the Mach number and flow coefficient of a single-stage are the same, the polytropic efficiency and head coefficient of the stage remain basically unchanged. According to the calculation, the head coefficient of the product is 42% higher than that of the parent stage, that is, the working capacity of the impeller is almost increased by 0.5 times. This calculation result does not conform to the similarity theory. And this series of impellers have been used in more than ten other reforming projects, and there has never been a similar situation. Therefore, from the perspective of the similar modelling design of the compressor, the accuracy of the compressor parameter test is in doubt.

## 3.3. Test Methods for Components

The deviation of rotational speed, inlet and outlet pressure, and temperature in the test data has been eliminated by testing in multiple positions, and the composition of the medium is also tested by the user by sampling multiple times, and the molecular weight of the medium is always lower than the design value.

After an in-depth discussion with users, we knew that the detection of medium components is performed through bladder sampling in the pipeline at the front of the compressor inlet. In bladder sampling, it’s possible that there are residual heavy components in the bladder, which will affect the test results. In addition, the user's testing instrument cannot accurately analyse the C5+ components. If the actual molecular weight is relatively larger, a higher pressure-ratio can be achieved with a lower rotational speed, which is closer to the actual operating situation. We gradually realized that the contradiction of the performance deviation of the two compressors lies in the testing method of the medium composition. The components measured by the user are shown in Table 4.

Table 4: Compressor medium components measured by users.

| gas composition | $H_2$ | $C_1$ | $C_2$ | $C_3$ | $C_3^=$ | $iC_4$ | $nC_4$ | $C_4^=$ | $C_5^+$ | total | molecular weight | method |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MOL % | 88.75 | 2.15 | 2.96 | 2.6 | 0.02 | 1.4 | 0.8 | 0.01 | 1.31 | 100.0 | 6.39 | bladder |

## 3.4. Inspection of Steam Consumption

The total medium pressure steam consumption of C201 and C202 units is 80 tons/hour. The processing capacity of the 2# reformer has reached the designed capacity, and the steam consumption is lower than the design value of 87 tons/hour. The energy source of the compressor is steam, and the energy consumption of the unit is based on the power consumption of the steam, indicating that the compressor does not have the problem of high-power consumption.

## 4. Third-party Testing

In order to verify the accuracy of the gas composition, we entrusted a professional testing agency to analyse the composition of the circulating hydrogen gas using the bladder and the steel cylinder for sampling several times. The related analysis data are compared in Table 5.

Table 5: Compressor medium components measured by a third-party testing agency.

| Data | $H_2$ | $C_1$ | $C_2$ | $C_3$ | $C_3^=$ | $iC_4$ | $nC_4$ | $C_4^=$ | $C_5^+$ | total | molecular weight | method |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| June 9, 2021 | 87.05 | 1.98 | 3.07 | 2.91 | 0.02 | 1.60 | 1.02 | 0.10 | 2.25 | 100.0 | 7.49 | bladder |
| | 83.32 | 1.88 | 2.99 | 2.98 | 0.02 | 1.68 | 1.24 | 0.07 | 5.82 | 100.0 | 10.14 | cylinder |
| June 10, 2021 | 85.61 | 1.96 | 3.12 | 2.98 | 0.02 | 1.67 | 1.13 | 0.07 | 3.44 | 100.0 | 8.46 | bladder |
| | 84.04 | 2.08 | 3.34 | 3.22 | 0.02 | 1.83 | 1.26 | 0.08 | 4.14 | 100.0 | 9.29 | bladder |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 85.80 | 1.96 | 3.14 | 2.98 | 0.02 | 1.67 | 1.12 | 0.07 | 3.24 | 100.0 | 8.31 | bladder |
| | 85.09 | 1.96 | 3.13 | 3.02 | 0.02 | 1.71 | 1.17 | 0.07 | 3.82 | 99.99 | 8.78 | bladder |
| June 11, 2021 | 86.80 | 1.94 | 3.06 | 2.88 | 0.03 | 1.59 | 1.02 | 0.05 | 2.63 | 100.0 | 7.76 | bladder |
| | 83.60 | 1.86 | 3.00 | 2.96 | 0.02 | 1.69 | 1.20 | 0.07 | 5.59 | 100.0 | 9.96 | cylinder |
| simulation | 85.60 | 2.15 | 2.11 | 2.01 | | 0.87 | 0.87 | | 6.39 | 100.0 | 10.02 | |

From the data in Table 5, the analysis data of the same sampling method are basically the same, and the composition difference between the bladder sampling and the cylinder sampling is in the hydrogen and $C_5^+$ components. The $C_5^+$ measured by the cylinder sampling accounts for a larger proportion, which is consistent with the fact that the pressure ratio of the compressor is high when the rotation speed is low, suggesting that the result of cylinder sampling is closer to the molecular weight of the actual medium.

Since deviation exists in the sampling and analysis process of industrial devices, the testing agency recommends that the molecular weight parameters used in the calculation of the orifice plate flow should be set according to the molecular weight calculated by simulation of 10.03 or the average of the results of 2 to 3 times of cylinder sampling and analysis at the same time.

## 5. Compressor Performance Recalculation

We then correct the flow rate of the orifice plate according to the molecular weight value recommended by the third-party testing agency. The flow rate calculated with a molecular weight of 6.39 is 104270Nm$^3$/h and should be corrected to 88466Nm$^3$/h. According to the composition of the medium provided by the testing agency, we recalculate the actual operating data of the reforming compressor. The calculated parameters and curves obtained are shown in Figure 2. At this time, the operating point has approximately fallen on the reforming compressor performance curve, which verifies that the accuracy of the molecular weight test results and the reliability of the compressor performance. In addition, the problem of the hydrogen booster compressor is the same as that of reforming compressor, therefore this paper does not list the calculation for the hydrogen booster compressor.

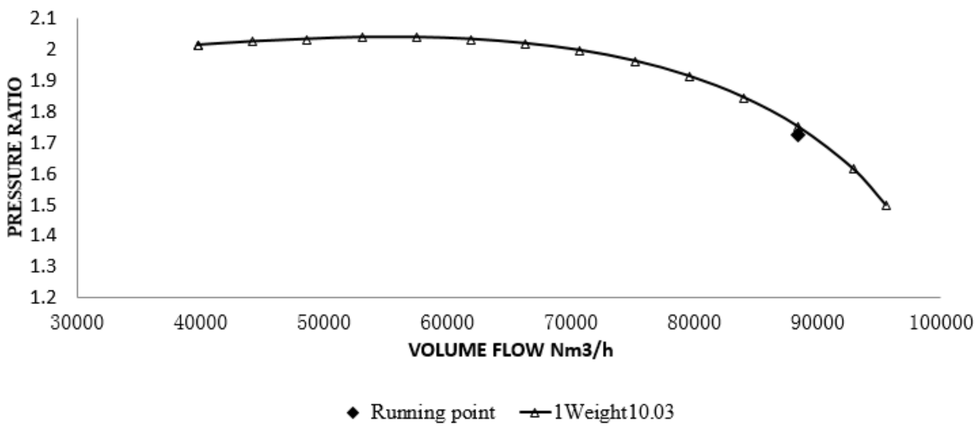


Figure 2: Simulated compressor performance curve according to molecular weight 10.03.

## 6. Conclusions

In this paper, by studying the performance of reforming Circulating hydrogen compressor in China Petroleum & Chemical Corporation Luoyang Branch, and following the basic working principle of the compressor, we determined that the root cause of the suspected deviation of the compressor performance is that the test value of the molecular weight of the medium is too small. With the assistance of a third-party testing agency, we carried out a more accurate detection of the medium components, which verifies that the analysed direction is accurate.

1) The medium components of reforming Circulating hydrogen and hydrogen booster compressors are relatively complex, and the molecular weight varies in a relatively large range with the change in raw materials.

2) For compressors with smaller molecular weight, the performance is greatly affected by the molecular weight. The precondition of evaluating the aerodynamic performance of the compressor is ensuring the accuracy of the test results, so as not to mislead the analysis conclusion.

3) When there are many components above $C_5$, we prefer the method of cylinder sampling for component detection.

4) The flow is an important parameter for the anti-surge protection of the compressor. Special attention should be paid to the flow test to avoid the protection failure of the unit due to the large deviation of the flow calculation.

## References


*[1] Li Niu. (2009) Selection and Control Analysis of Circulating Hydrogen Compressor and Booster Unit in Reformer. Refinery Technology and Engineering, 39(04), 31-34.*

*[2] Jian-xin Zhang. (2012)Analysis on Circulating Flow Rate and Relative Parameters Fluctuation of Circulating Hydrogen Compressors. Contemporary Chemical Industry. 41(08),859-861.*

*[3] Lei, Tan, Wang. (2021)Cause Analysis and Treatment of Inlet Flow Fluctuation of Circulating Hydrogen Compressor. Technology & Development of Chemical Industry.8,65-66.*

*[4] Wang, Chen. (2009)Failure Analysis of BCL605-1 Centrifugal Compressor and the Improvement. Petro-chemical Equipment.38,82-85.*

*[5] Chen, LIU, Yang. (2016)Optimization and Applications of Circulating Hydrogen Compressor Performance Curve. Application and Test.6, 38-41.*

*[6] Zhong Xu. (1990) Principle of Centrifugal Compressor. Beijing: Machinery Industry Press.*