47TH TURBOMACHINERY & 34TH PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 17-20, 2018
GEORGE R. BROWN CONVENTION CENTER

DEVELOPMENT OF NEW ON-LINE WASH OIL INJECTION SYSTEM FOR CENTRIFUGAL COMPRESSOR

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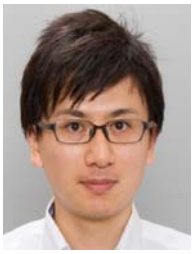

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ABSTRACT

The process gas compressor is the most critical unit in an ethylene plant and several types of contaminates can often foul the compressor flow path, causing deterioration in performance and significant losses in plant production. In order to prevent the efficiency losses due to this fouling during long term operation, as common practice, washing oil is injected through the nozzles installed on the suction piping and return bend of each stage.

However, fouling material has been reported during turnaround with few years of operation even though wash oil injection has been carried out at required intervals. Hence, user and OEM carried out CFD (Computational Fluid Dynamics analysis) to investigate the conventional design process and its practical effect to washing capability. And OEM found the effective approach to develop the new concept improving on-line wash oil injection system.

Optimized oil injection system which includes new injection location, injection hole size, injection angle and oil quantity were evaluated with consideration to prevent any risk including erosion by droplet, any leakage through newly designed part and etc. by means of CFD and FEM(Finite Element Method) analysis. Evaluation through numerical approach was verified through subsequent verification test using actual component and fully assembled machine according to the newly developed design. And every analysis was confirmed to work as intended.

After completion of these investigations, OEM manufactured and delivered newly developed oil injection system in user site where the fouling materials on the compressors were reported with conventional oil injection system. And after a few years commercial operation, User and OEM confirmed the effectiveness of newly developed system at site by checking the compressor performance.

INTRODUCTION

Fouling of the process gas compressor is considered to be caused, as shown in the Fig.1, by the reaction of compressed gas in condition that its temperature exceeds a certain level. This fouling leads performance degradation of compressor and increases user's power consumption to keep intended plant production plan. OEM implements water injection to each of the compressor stages to reduce the gas temperature in order to prevent this fouling, but it is practically impossible to completely eliminate the fouling possibility. Hence, on-line wash oil injection system is also included in the process gas compressor package. This conventional oil injection system installed on the compressor casing is shown in Fig.2.
OEM found that there was the room to improve the washing capability through the verification with the user's turnaround report and OEM developed new concept of on-line wash oil injection system. This paper introduces the detailed process toward establishment of this development.

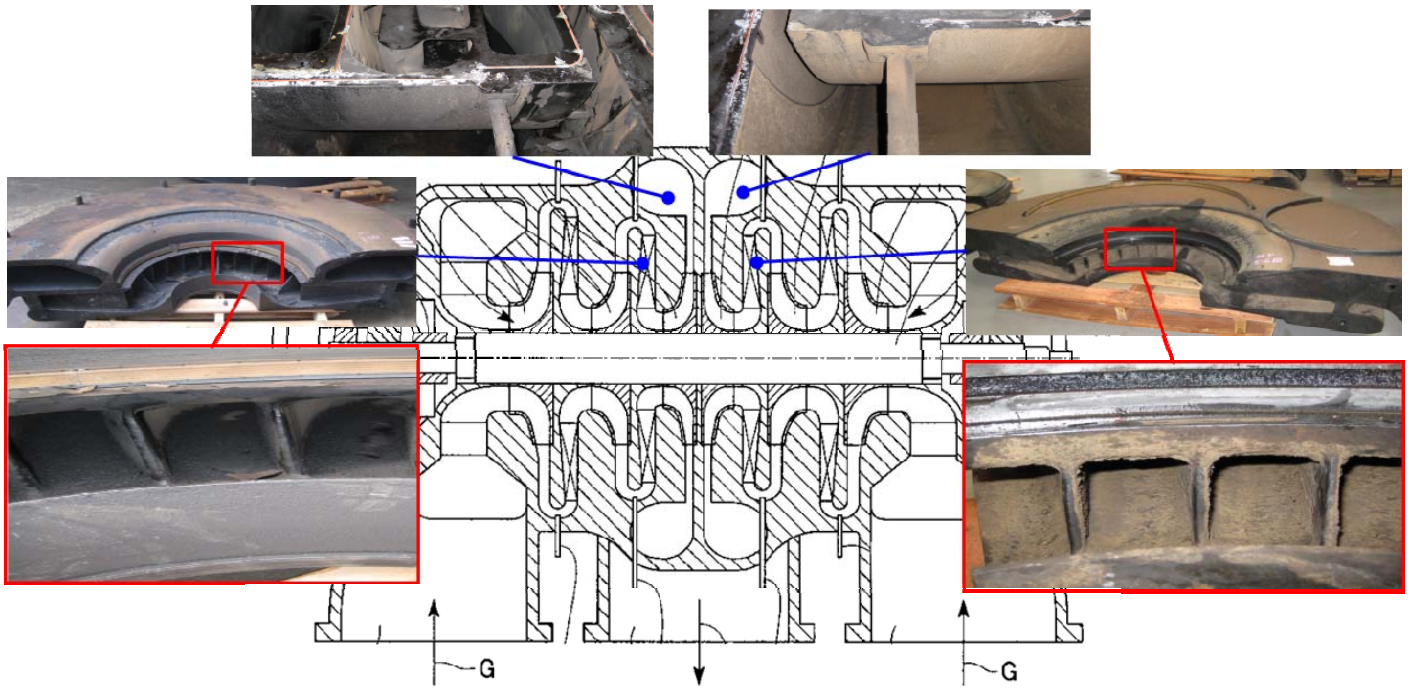


Fig. 1 Fouling condition found at user site

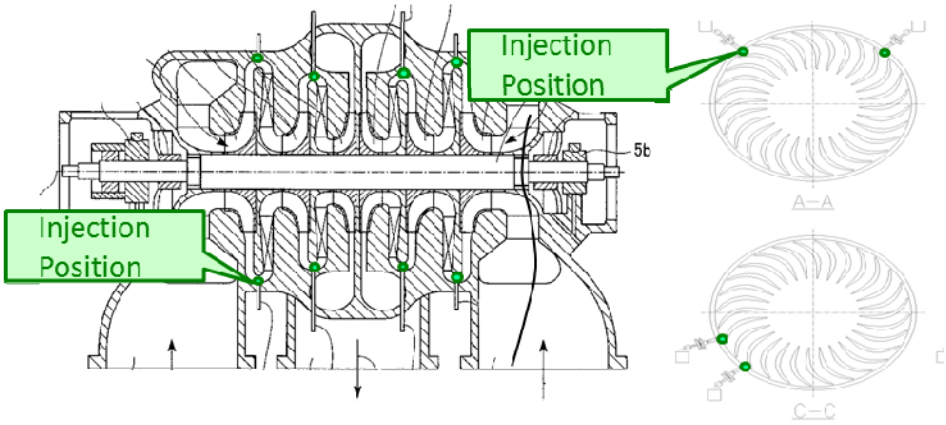


Fig. 2 Conventional wash oil injection system configuration

DEVELOPMENT APPROACH

The step toward establishment of new on-line wash oil system is shown in the Fig.3. Investigation of conventional wash-oil injection system was carried out to understand the current cleaning capability. Based on this study, improved new concept was considered through CFD analysis. Then, new concept of wash oil system was verified by the test using the component test at first and subsequently the whole compressor machine. And new system was assessed from the view point of possible risk at site and its mitigation plan. Finally, the actual washing oil system was implemented in the actual compressor and it was delivered at user plant. The operating data proved that newly developed on-line wash system worked as intended and OEM development was found successfully completed. The more detail of each steps are described in the following paragraphs.

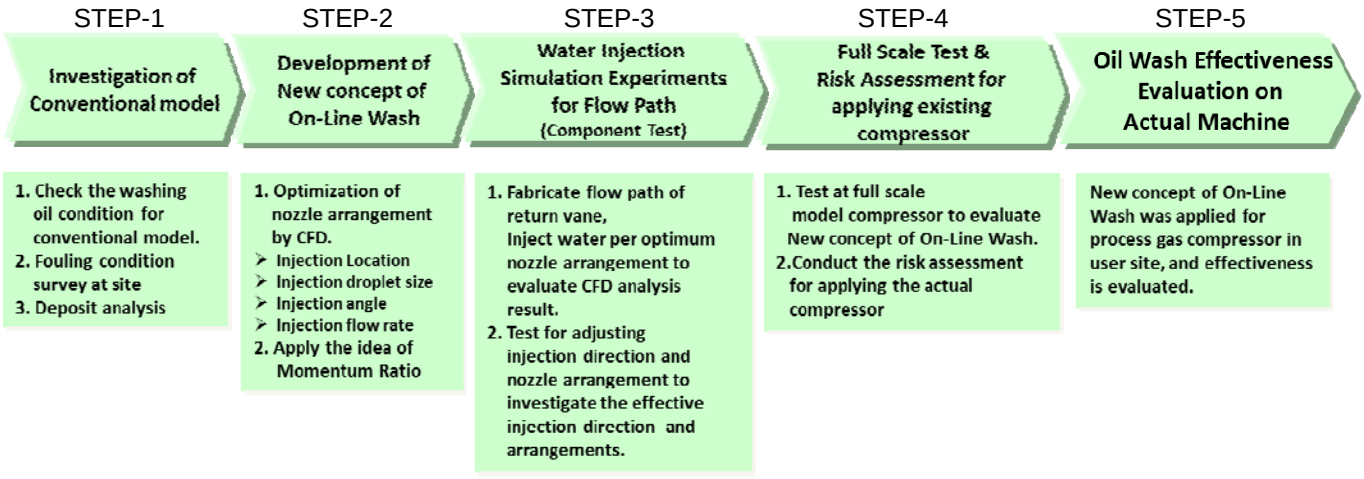


Fig. 3 Step of development of new concept on-line wash oil system

STEP-1. INVESTIGATION OF CONVENTIONAL MODEL

OEM investigated the conventional system through CFD analysis to explain the condition reported by user. As a result, it was found that injected washing oil might not have been equally distributed along the whole gas passage area as shown in Fig.4. Therefore, OEM investigated new design concept to enhance the distribution equality so that washing oil can reach all the gas passage area.

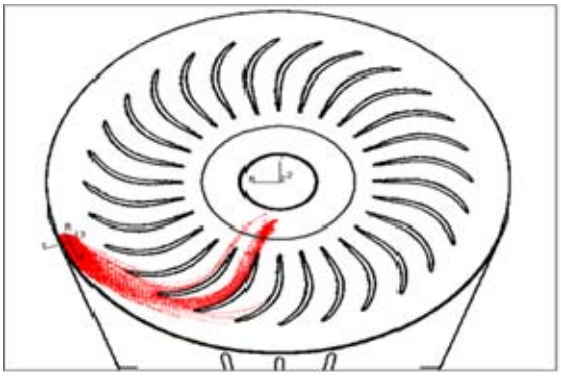
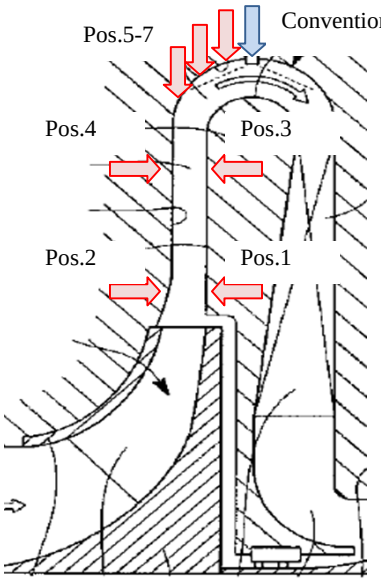


Fig. 4 Expected injected oil flow line from single injection nozzle

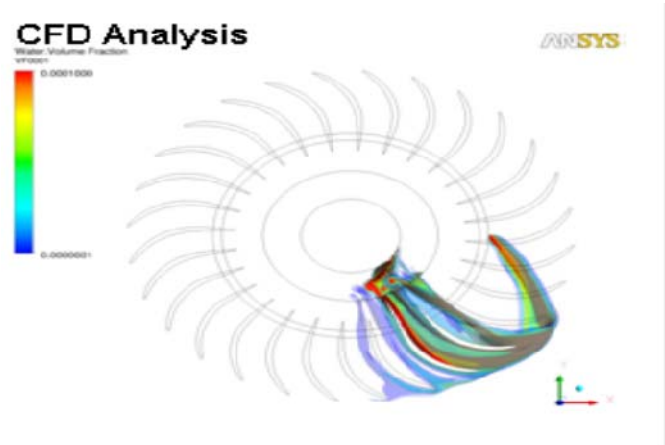
STEP-2. DEVELOPMENT OF NEW CONCEPT OF ON-LINE WASH

The case study was carried out to find the optimized design to maximize the cleaning capability of on-line wash oil system. Various injection locations, droplet sizes, nozzle angles and flow rates were taken into consideration as shown in Fig.5. This case study revealed that injection at near impeller tip from impeller hub side, Pos.1, was the best position from the view point that injected oil mist can be distributed equally along with flow path. CFD analysis result of Fig.6 shows improved injected mist distribution compared with conventional system and it can be understood that injected mist reaches approximately 1/12 of flow passage area from single injection point. Hence, OEM decided to implement totally 12 injection holes in the diaphragm as shown in Fig.7 to enable wash oil mist distribution to whole the gas passage area.



Case	Nozzle Hole Diameter	Velocity	Injection Direction	Location
1 RSCT	1mm	24m/s	Inclined	Diffuser Center
2 RDST	1mm	24m/s	Inclined	Diffuser Shroud
3 RDHT	1mm	24m/s	Inclined	Diffuser Hub
4a DST	1mm	24m/s	Inclined	Diffuser Exit Wall Shroud Surface
4b DHT	1mm	24m/s	Inclined	Diffuser Exit Wall Hub Surface
5 IST	1mm	24m/s	Inclined	Impeller Exit Shroud Surface
6 DHV	1mm	24m/s	Perpendicular	Diffuser Exit Wall Hub Surface
7 IHV	1mm	24m/s	Perpendicular	Diffuser Inlet Wall Hub Surface
8 ISV	1mm	24m/s	Perpendicular	Diffuser Inlet Wall Hub Surface
9 IHT	1mm	24m/s	Perpendicular	Diffuser Inlet Wall Hub Surface
7'IHV	1mm	32m/s	Perpendicular	Diffuser Inlet Wall Hub Surface
7'IHV	1mm	45m/s	Perpendicular	Diffuser Inlet Wall Hub Surface
7'IHV	0.5mm	32m/s	Perpendicular	Diffuser Inlet Wall Hub Surface

Fig. 5 Case study of oil injection for optimization



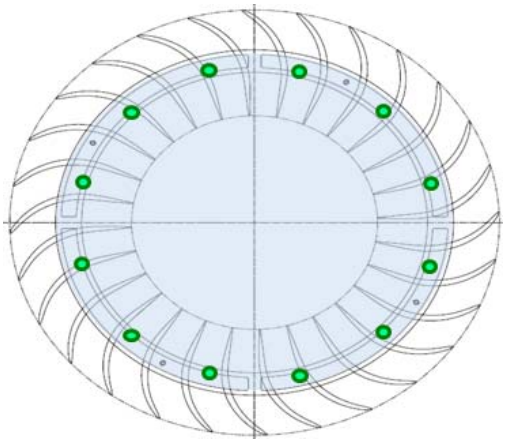
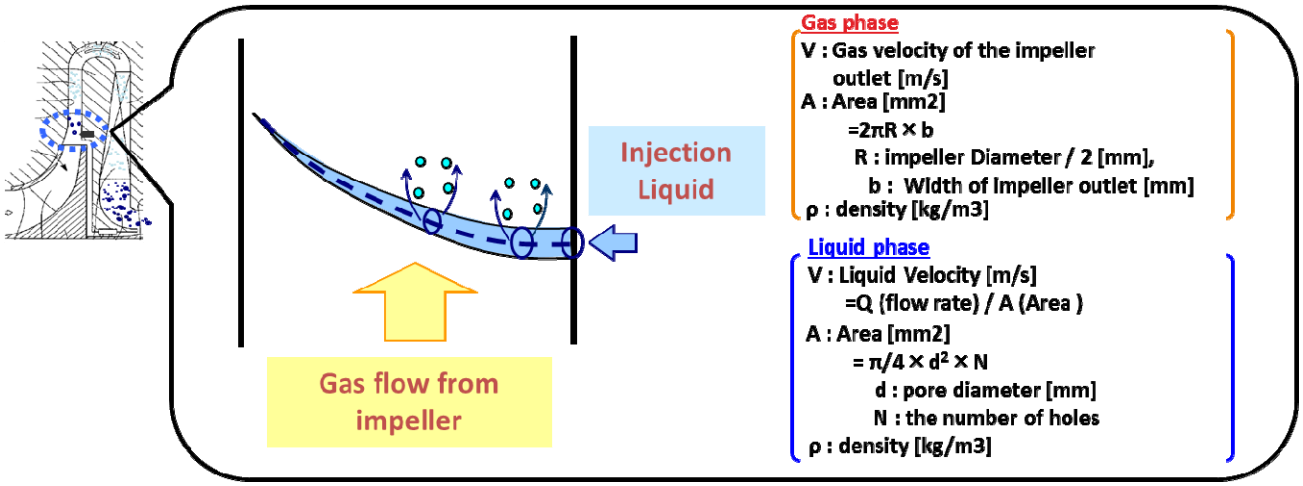


Fig. 6 CFD analysis result of oil injection at Pos.1 (Left)
Fig. 7 Wash oil Injection nozzle arrangement based on newly developed concept (Right)

As for the injection flow rate, it was optimized by adjusting momentum ratio of gas phase and liquid phase. Simplified model is shown in Fig.8. Optimum flow rate was considered from the stand point of capability to equally distribute the oil mist. CFD analysis result showed that higher liquid flow rate to the gas flow rate is better. Meanwhile, OEM simultaneously considered the risk of erosion and performance decrease due to increased total gas flow and finally established the optimal amount as standardized value covering the all of these perspectives.
Bottom of Fig.8 shows the case study result of momentum ratio. Accordance to the increased liquid flow, distribution area was increased but it was found to be saturated at the certain level. OEM decided that low liquid momentum ratio case, in this table, is the optimum condition from the all of the perspective.

< Concept of momentum ratio >



< Case study of momentum ratio >

Process Gas Flow

Liquid Injection Flow

Momentum ratio	Measurement points			
	Very High	High	Low	Very Low
Very Low	65 degree	65 degree	65 degree	90 degree
Low	90 degree	90 degree	90 degree	130 degree
High	115 degree	115 degree	115 degree	Data not available
Very High	115 degree	Data not available	115 degree	Data not available

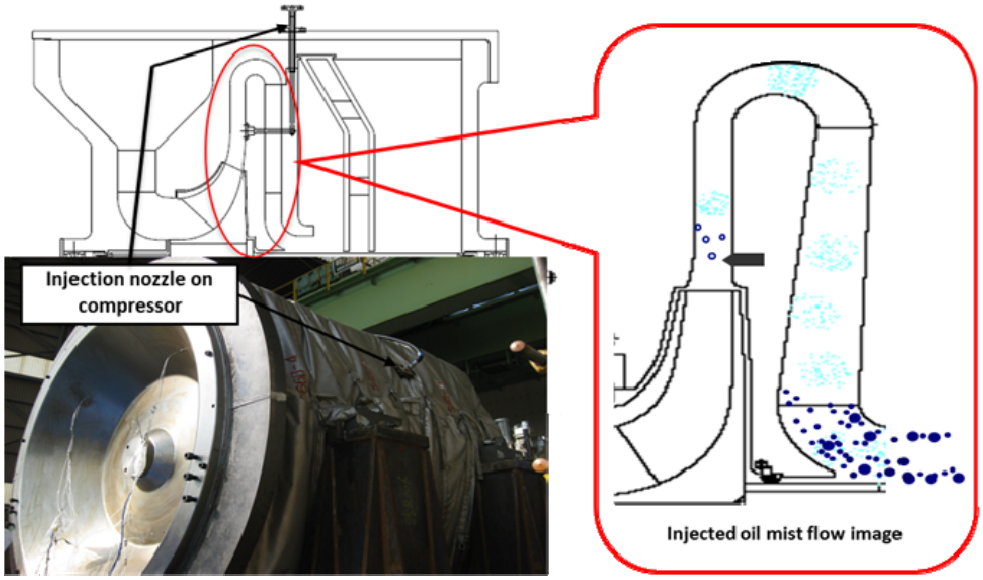
Fig. 8 Concept of momentum ratio

STEP-3&4 VERIFICATION TEST OF DEVELOPED NEW CONCEPT

In order to verify CFD analysis result, test by means of components and whole compressor machine was conducted. Fig.9 shows the arrangement of this verification test. Water injection was used to represent injected wash oil and temperature measurement enabled visualization of the mist distribution by sensing of compressed gas temperature decrease
Fig.10 shows the test result showing injection nozzle location and measured mist distribution. At the both of component and full

assembly test, approximately 40 degree distribution per injection nozzle was found as highlighted in pink in this figure. CFD analysis result shown in Fig.6 well agreed with this verification test result. Then, OEM confirmed that CFD analysis was calculated under the reasonable condition and result was reliable.

<Injection nozzle installation>



<Temperature sensor location>

Fig. 9 Verification test arrangement

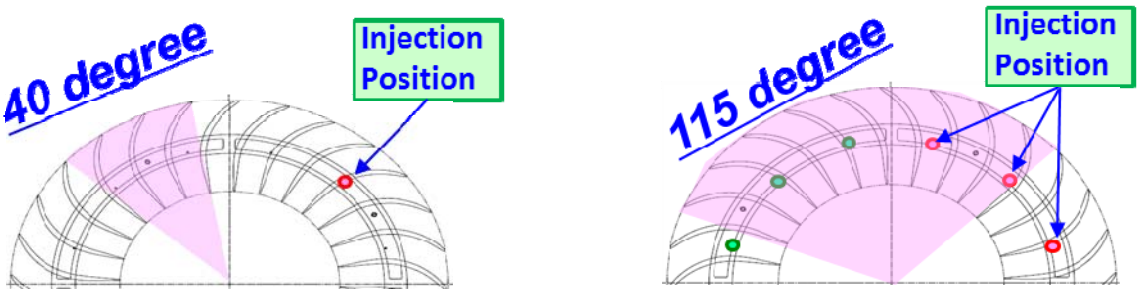


Fig. 10 Verification test nozzle location(pink circle) and distributed area(pink area)

RISK ASSESMENT OF DEVELOPED WASH OIL INJECTION SYSTEM

Any risks related to the components newly developed were evaluated from the perspective but only one point is introduced as example for understanding the procedure which was taken. As shown in Fig.2 and Fig.5, injection location was changed from return bend to the diaphragm of each stage. Due to this change, unintended oil leakage through diaphragm was considered as the possible failure mode. Fig.11 shows the structure of diaphragm at horizontal split surface. This failure mode could be caused by the insufficient sealing at diaphragm and would lead to the increased injection oil flow rate and less plant production due to insufficient washing and increased mass flow rate. This failure mode can be detected by the flow meter implemented on the piping upstream of wash oil injection nozzle. Performance data would also be the means of the detector of this failure mode. In order to prevent such failure, OEM carried out FEM analysis to check stress distribution in diaphragm caused by pressured wash oil. And also OEM conducted in-house testing to verify the sealing is functioning as designed.

Following table shows the summary of the process as described in the above. Every possible risks and risk mitigating plan for each of items were considered and summarized before this new design concept was deployed to the actual product to prevent any trouble at site.

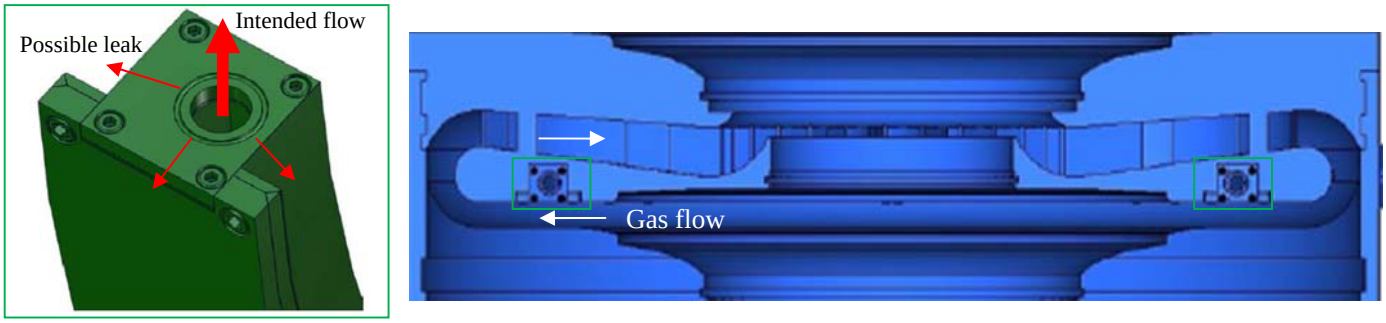


Fig. 11 Structure of diaphragm at the horizontal split surface

Table. Risk assessment summary for leakage at diaphragm horizontal split surface

Component	Fail Mode	Cause	Impact by Fail	Fail Detection	Fail Prevention
Diaphragm	Oil Leakage from horizontal split surface	Insufficient sealing	Increased flow rate	Flow meter	1. Calculation of hydraulic pressure of oil (internal press) and weight of upper side diaphragm(sealing press) 2. Leakage check during in-house hydrostatic test.
			Degraded plant production	Performance data	

EFFECTIVENESS EVALUATION ON ACTUAL MACHINE

Improved compressor with new wash oil injection system was delivered to user site, where the performance degradation was reported. Fig.12 shows long term operating data of compressor efficiency including before and after replacement with new oil injection system. This trend shows performance getting worse along with the time of operation before modification of wash oil injection system. However, it can be seen that performance improvement after implement of new wash oil injection system and no further performance degradation even after 30 months operation. This trend data ensure that new wash oil injection system is working as intended.

Actual fouling condition is going to be confirmed during the next turnaround of user plant.

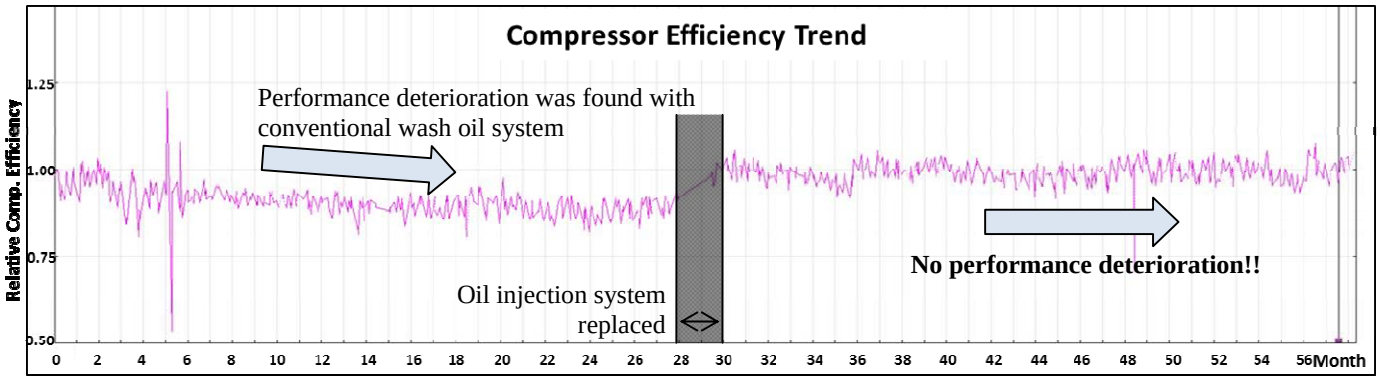


Fig. 12 Efficiency trend data through long term operation (before and after oil injection system replacement)

CONCLUSIONS

CFD analysis was carried out to decide optimized configuration of wash oil injection to facilitate the distribution of oil mist all along the gas passage area inside centrifugal compressor. As a result, OEM found optimized design as below.

1) Injection at the nearest point of impeller tip
2) Injection from the hub side to shroud side
3) Optimum momentum ratio (Gas phase/Liquid phase)

The verification test by means of compressor component & whole machine was carried out to verify the CFD calculation result and OEM confirmed that the verification test result had good compatibility with the founding of CFD calculation. And also, developed system was installed on actual compressor and operating trend data more than one year proved the new wash oil system is working as intended.

As a result of these investigation, OEM successfully established the new concept of enhanced On-Line wash oil injection design.

REFERENCES

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ACKNOWLEDGEMENTS

The authors gratefully wish to acknowledge the following individuals for their thoughtful suggestions, contribution and technical assistance in analyzing and sharing valuable experiences.

- A. Mathew of Lead Machinery Engineer of Engineering Services Department at ExxonMobil Chemicals
- E. Subramani of Machinery engineer at ExxonMobil Research Engineering
- A. Nakaniwa of Mitsubishi Heavy Industries Ltd