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Reliability Improvement for Booster Reciprocating Compressor in CCR Reformer

Sanguk Lee / Bumsu Kim
Sangsuk Lee / Sangjoo Lee

SK energy

TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

TEXAS A&M UNIVERSITY

Presenter/Author bios

Presenter, Mr. Sanguk Lee.

Rotating machinery engineer in reliability for SK Energy Ulsan, Korea, since 2012.

Received a B.S.degree (Mechanical Engineering from Busan National University, Korea).

Experience includes troubleshooting for compressor and vibration diagnosis in refinery and petrochemical plants.

In charge of this case study for reciprocating compressor for six years. Present a lesson learned based on hands on experience.

Co-author. Mr. Bumsu Kim.

Rotating machinery specialist in reliability for SK Energy Ulsan, Korea, since 1997.

Received a B.S.degree (Mechanical Engineering from Busan National University, Korea) and a key member of KRMEA(Korea Rotating Machinery Engineers Association).

Co-author. Mr. Sangsuk Lee.

Joined SK Energy as mechanical engineer in 1994.

Received a B.S.degree(metallurgical engineering from Yonsei University, Korea) and a key member of KRMEA(Korea Rotating Machinery Engineers Association).

Co-author. Mr. Sangjoo Lee .

Rotating machinery engineer in reliability for SK Energy Ulsan, Korea, since 2007.

Received a M.S. degree(Mechanical Engineering from Ulsan University) and a key member of KRMEA(Korea Rotating Machinery Engineers Association)

Presentation Overview

1. Abstract
2. Problem Overview
3. Troubleshooting
4. Recommended Solutions and Results
5. Lessons Learned

1. Abstract

CCR(Continuous Catalyst Regeneration) Reformer process inherently creates viscous liquid called green oil*. When reciprocating compressor are selected as booster compressor for process, green oil creation and carry-over must be taken into consideration.

This case study includes root cause analysis & its countermeasures in various aspects of process, mechanical design, condition monitoring system. It is based on actual experience to improve the reliability of the compressor in CCR Reformer.

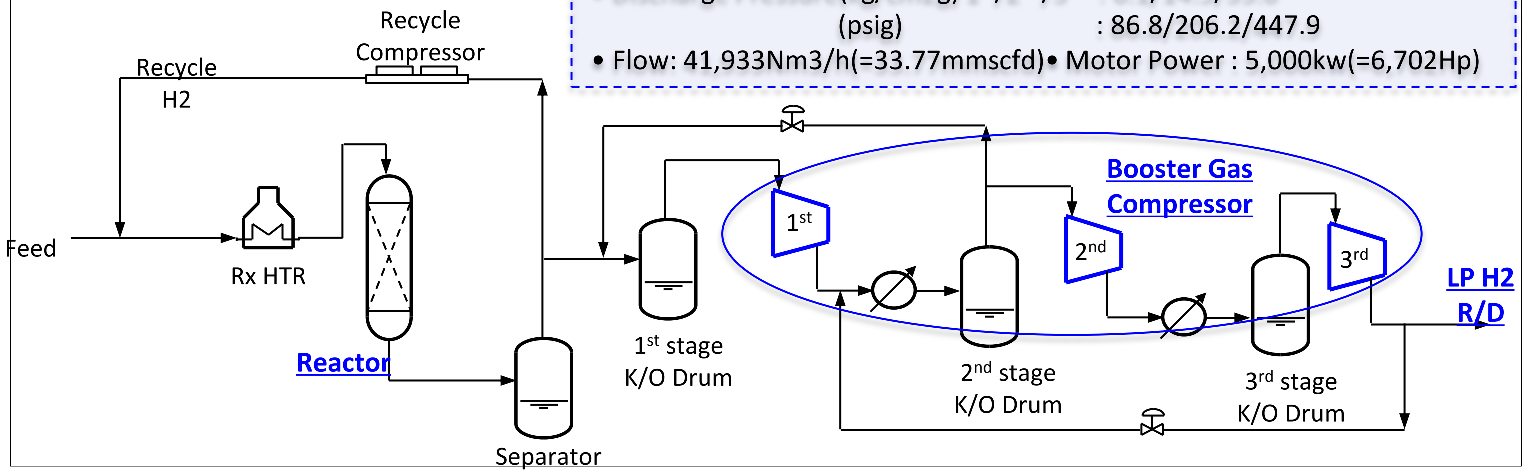
* green oil formation

- green oil is formed by oligomerization or polymerization of light olefins and is catalyzed by acidic conditions(FeCl2+HCl).
- green oil forms easily at high pressure and temperature.

Compressor System & Specifications

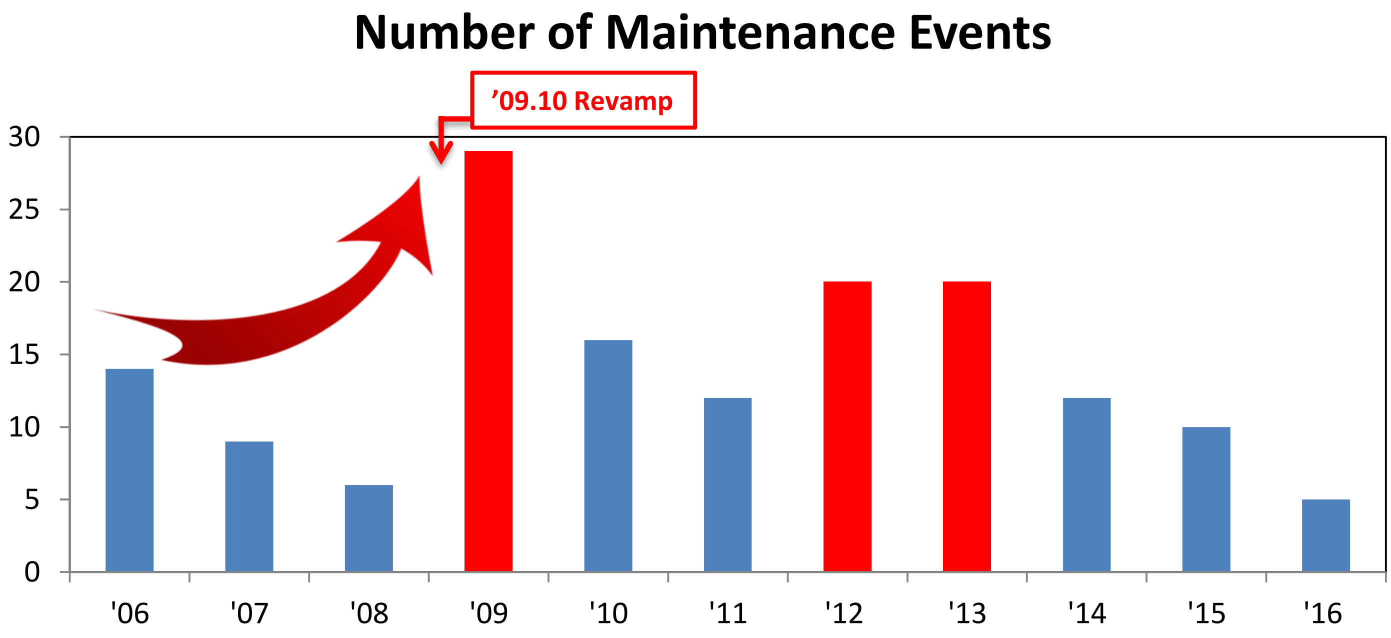
Installed in 2005, the booster compressors in CCR Reformer process **transfer** rich hydrogen(H2) gas from reactor to H2 plant.

- Number of Compressor : 3ea
- Number of Stage / Cylinder : 3 stage / 4 cylinder(=number of piston)
- Speed(rpm) : 400
- Suction Pressure (kg/cm2g) 1st/2nd/3rd : 2.1/5.7/14.0
  (psig) :29.8/81.1/199.1
- Discharge Pressure(kg/cm2g) 1st/2nd/3rd : 6.1/14.5/33.6
  (psig) : 86.8/206.2/447.9
- Flow: 41,933Nm3/h(=33.77mmscfd)• Motor Power : 5,000kw(=6,702Hp)



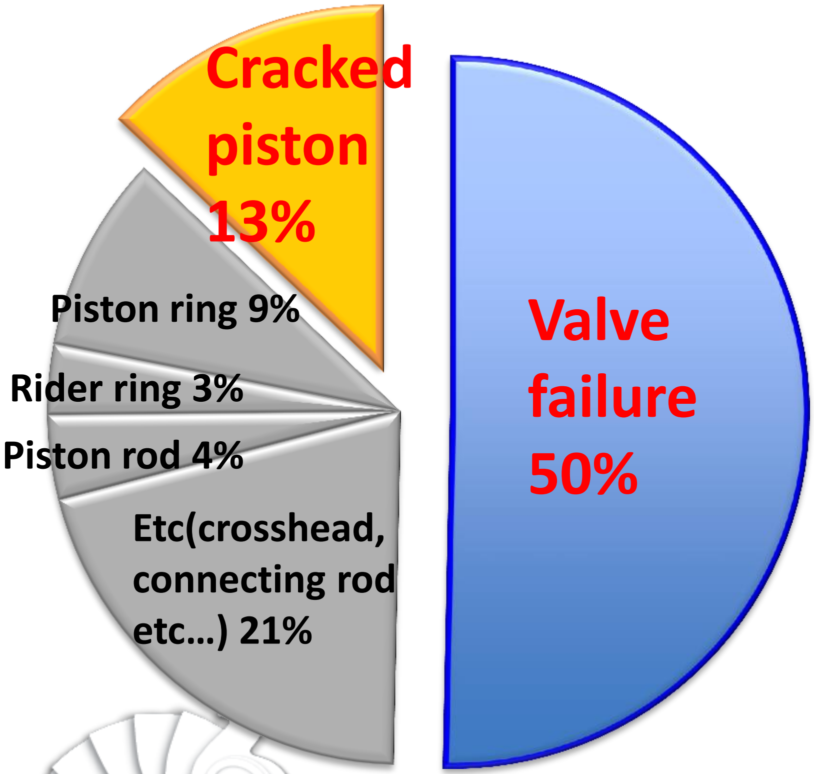
2. Problem Overview

Since process revamp in 2009, all three compressors have run without stand-by and the number of compressor troubles increased drastically.

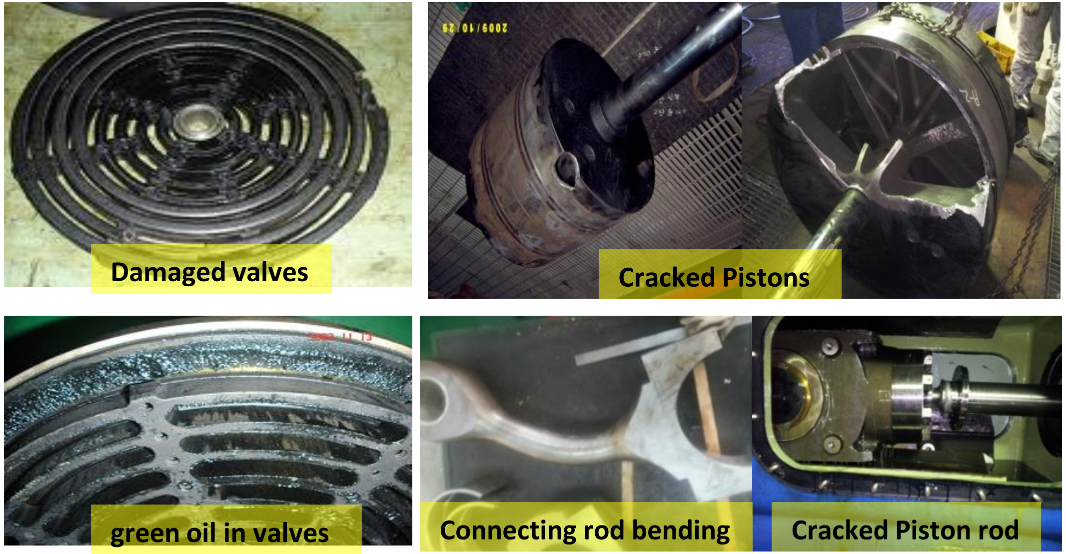


2. Problem Overview

2009~2016 Damaged Parts



Most problems or issues involved damaged valves and cracked pistons.



3. Troubleshooting

To find the possible cause of the problem, every aspect in the process was reviewed as well as the mechanical design and integrity.

Problem	Possible Cause	
Valve Failure	Process	Mechanical Design
Cracked Piston		Mechanical Design and Integrity

Process

- Increased generation of green oil after revamp.
- Main cause, but CCR reformer process inherently creates green oil.

Mechanical Design

- Ring type is not strong enough to endure foreign substance(green oil).

Mechanical Design and Integrity

- For piston to float (Free Floating Piston), it is made of a light (low density) material but its mechanical strength is low. Due to green oil, pistons could not endure additional stress (larger than design).

3. Troubleshooting

Process – Pressure & Temperature

Since process revamp in 2009, Booster Compressor's operating condition changed little, though well within operating range. Pressure ratios did not change much; however, discharge temperatures were higher than normal, yet below alarm set point T (145 ℃=293 F).

		Before revamp	After Revamp
Compressor at operating		2 run out of 3	**3 run out of 3**
Total Load	Nm3/h	80,983	**102,648**
	mmscfd	65.21	**82.66**
Pressure Ratio 1st/2nd /3rd Stage		2.20/2.39/2.31	**2.24/2.41/2.32**
Discharge Temperature 1st/2nd /3rd Stage	℃	105/101/106	**112/106/113**
	F	221/213.8/222.8	**233.6/222.8/235.4**

3. Troubleshooting

Process – Light Olefin, Rust

Changed the operating condition, the rust (Fe_2O_3) and Cl_2 dust increased green oil.

	Before revamp	After Revamp
H2/HC Ratio*	High	**Low**
green oil		**green oil increased** 

* H2(Hydrogen)/HC(Hydro Carbon) Ratio in process gas composition.

< Possible Cause of green oil forming >

- **Increasing light olefin**

  Decreasing H2/HC Ratio increases light olefins.

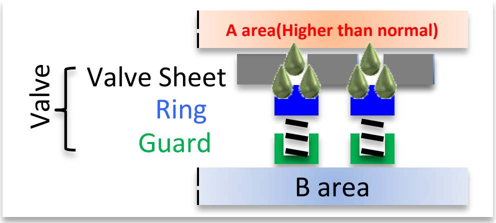
- **Increasing seeds of green oil like Rust and Cl2 dust**

  - Rust(Fe_2O_3) generated in the pipe by exposure to the atmosphere during turnaround.
  - Cl_2 dust is created during initial period of start-up and by using new catalyst.

3. Troubleshooting

At the initial design stage, a ring type discharge valve was used.

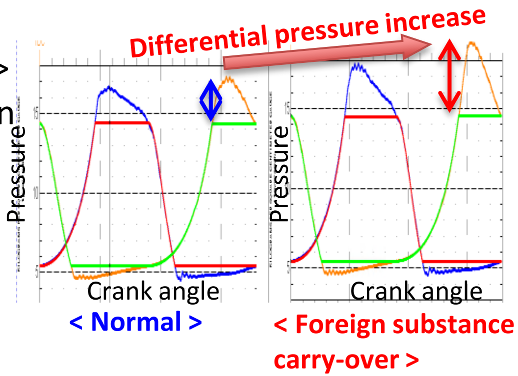
A ring type discharge valve is not strong enough to endure foreign substances.

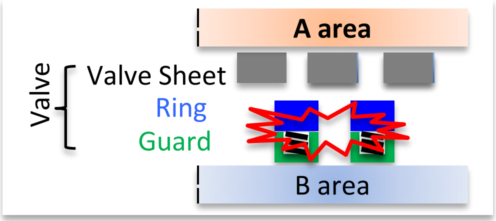


<In case foreign substance carries-over discharge valve>

Step1. Sticking occurs due to foreign substance between valve sheet and ring.

Step2. Late opening and differential pressure increase between A area and B area.





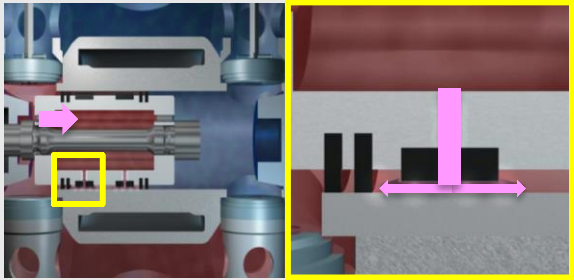
Step3. Increase impact and tumbling between ring and guard.

(because outer ring's stiffness is lowest, outer ring breaks easily.)

3. Troubleshooting

In order to float the FFP(Free Floating Piston), it is made of light weight material. However, the material strength is not large enough to withstand the large stress exerted by green oil (larger than design one).

< Characteristic of FFP >

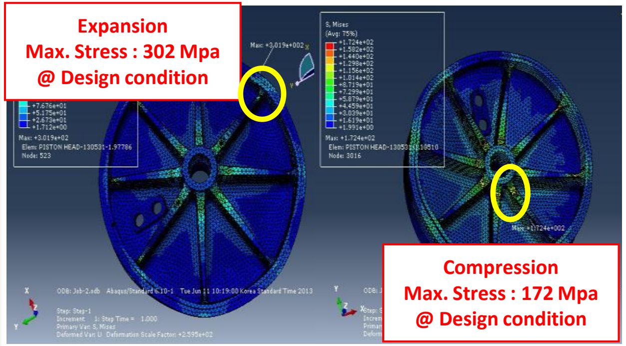


To prevent wear of rider ring, piston must float during operation. Discharge pressure jets on the bottom side between piston and liner.

Expected Actual Strength

Because of **increasing pressure due to green oil .** Actual Stress is higher than design.

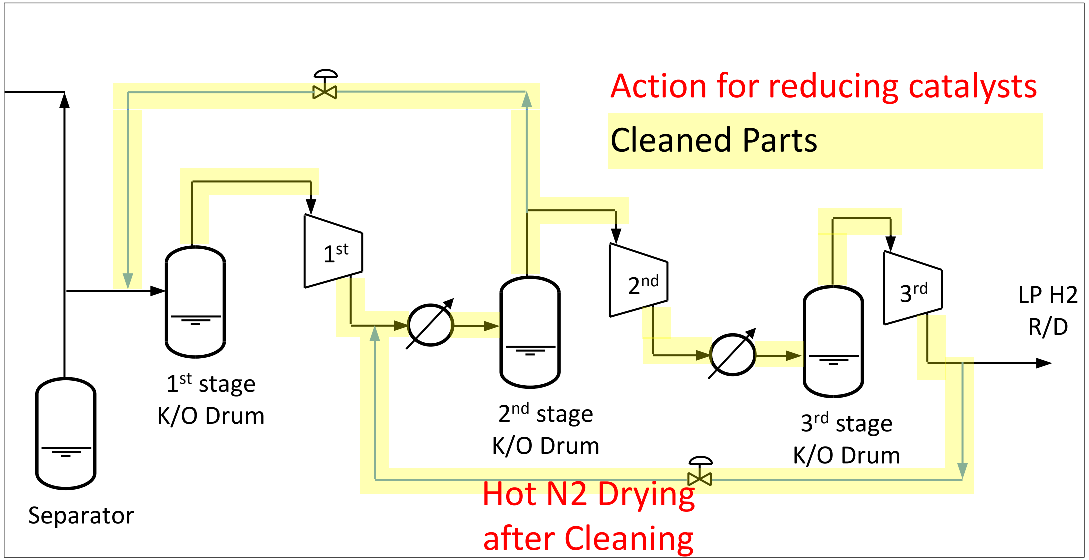
Piston Yield Strength(520~630Mpa)



4. Recommended Solutions and Results

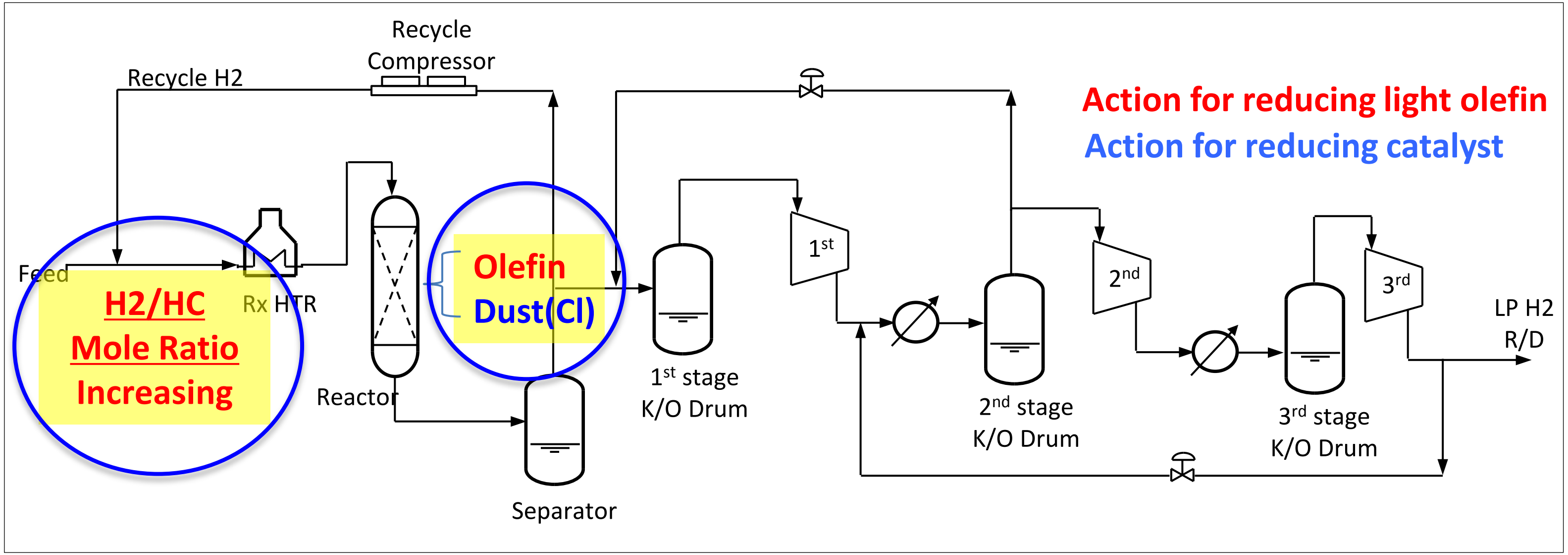
To avoid further generation of green oil, during plant turn around, catalysts like $Fe2O3$ and Cl (chlorides) were completely purged from the piping system, from the knock out drum to the discharge line.

< Cleaning Picture>



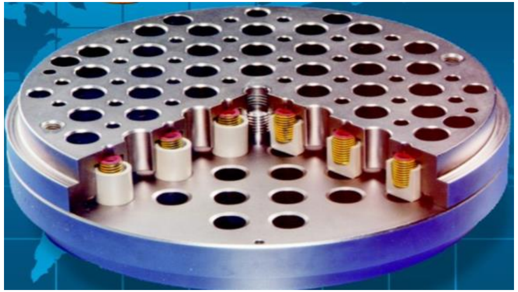
4. Recommended Solutions and Results

After turn around, to minimize forming green oil, the Reformer process reduced light Olefin. Further, to reduce Chloride(Cl), the operating condition was adjusted during the start-up period.



4. Recommended Solutions and Results

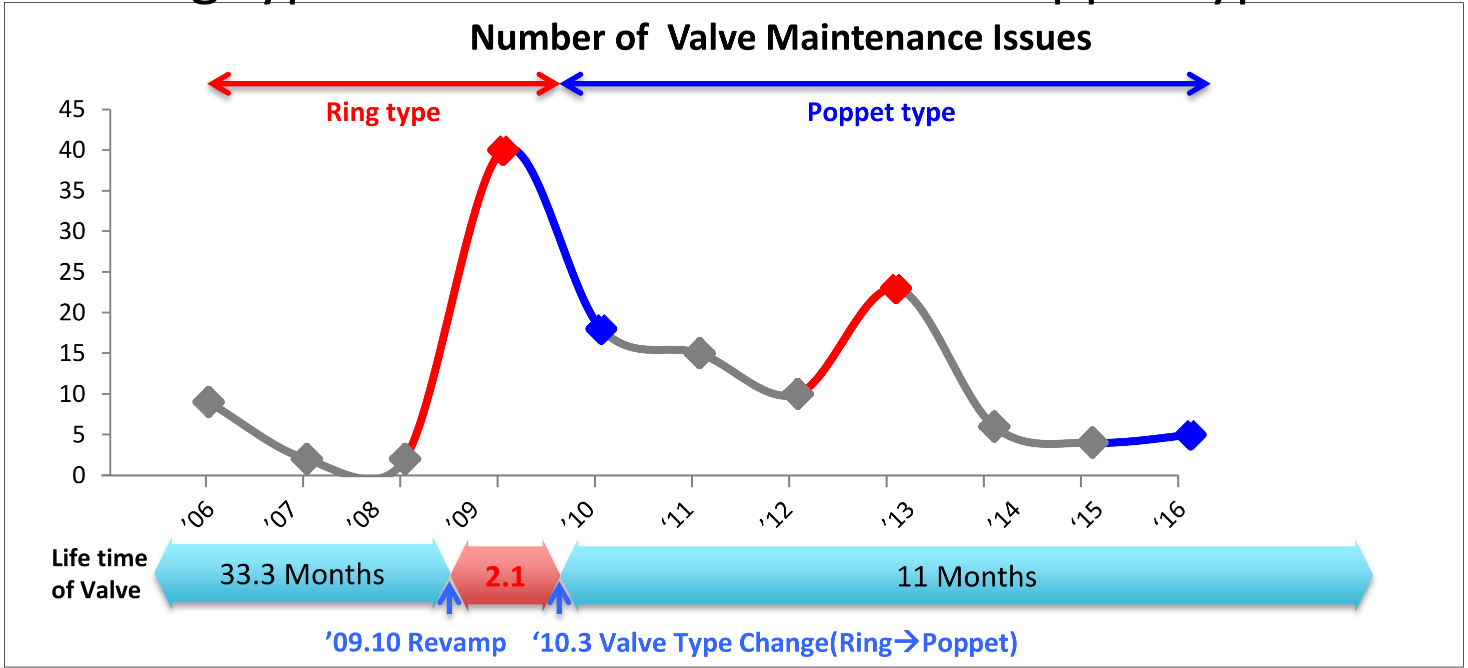
Replaced original valves with a Poppet type valve, which have high reliability in liquid carry-over and sticking.

	Ring Type	Poppet Type
Appearance		
The pros and cons	- Tight Sealing - High Efficiency **- Weak to accumulation of foreign substance** **- Low strength of outer side ring** **- High price**	- Because of increasing passing area, friction loss is little higher. - Advantage of inventory control **- Higher Stiffness** **- Strong against Sticking**

4. Recommended Solutions and Results

Mechanical Design - Valve

Discharge Valve Type changed from ring type to Poppet type in March of 2010. The mean life time of valve increased from 2.1 months with ring type to over 11 months with Poppet type.



4. Recommended Solutions and Results

Improve the geometry of a piston to increase its mechanical strength. As the material and method of production changed, the strength increased ~48% above original and without weight change.

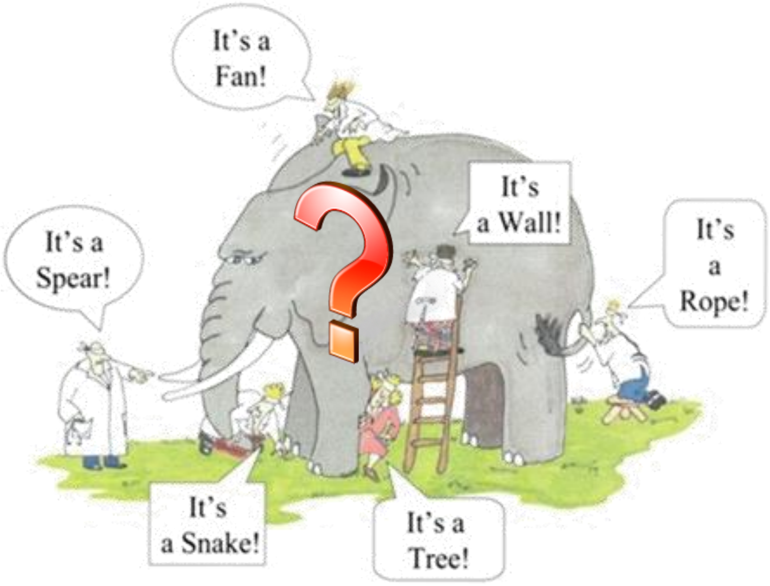
- **Improve the geometry**
  (Profile of rib and its thickness)

- Method of production **from casting to forging** (strength increased about 26%)
- **Improve the material** (increased about 18%)

EN Standard	Yield Strength [MPa]	Tensile Strength [MPa]	Elongation [%]	Hardness [HRC]	Charpy Impact Value [J] (min)
Original Material (X3CrNiMo13-4)	520~630	650~810	18~24	16~24	80 (50)
Improvement Material (X4CrNiMo16-5-1)	**550~810**	**760~960**	**16~22**	**24~32**	**190 (70)**

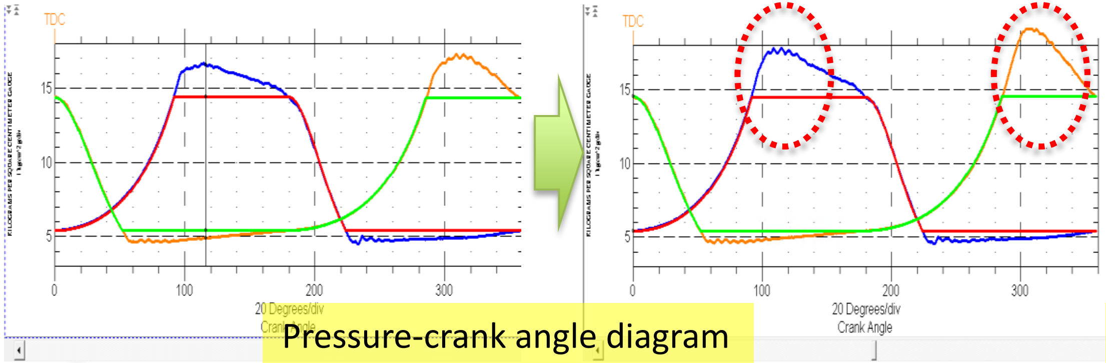
4. Recommended Solutions and Results

The original condition monitoring system could monitor only frame & crosshead vibration and simple process conditions(Suction & differential pressure, discharge temperature). Precision diagnosis could not be done due to the limited system.

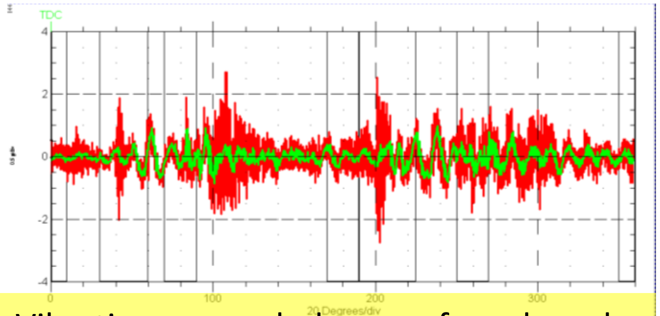


4. Recommended Solutions and Results

Built in ad-hoc reciprocating compressor monitoring and diagnosis system. It included measuring and logic for installed cylinder pressure indicators, rod position and multi-key phasor. System can perform precision diagnosis through P-V diagram and monitoring vibration per each degree of crank angle.



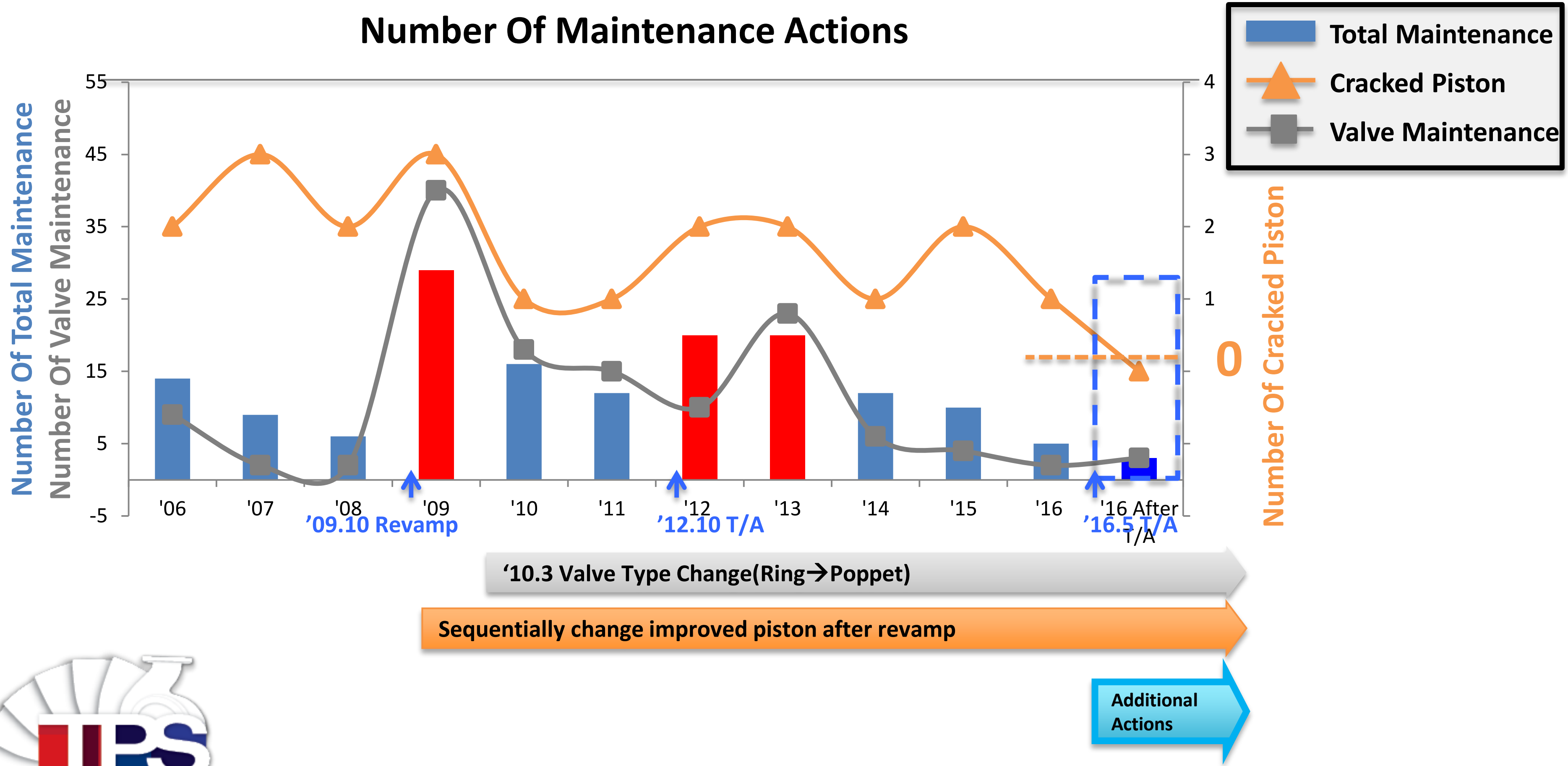
Pressure-crank angle diagram



Vibration per each degree of crank angle

4. Recommended Solutions and Results

Result



5. Lessons Learned

In CCR Reformer process, as long as the process can accept it, it is important to select centrifugal compressors instead of reciprocating compressors during construction of the plant.

If reciprocating compressors were selected, the following countermeasures should be taken into consideration.

a) Process

- To set up optimized operating condition to minimize liquid carry-over.
- To purge the piping system to reduce catalysis of green oil after turn around .

5. Lessons Learned

b) Mechanical Design

- If there are not any restrictions, cylinder lubrication type is recommended.
- If FFP(Free Floating Piston) is selected, strengthening of the piston should be performed.
- To select advanced valve type.(Poppet)

c) Condition Monitoring System.

- To consider monitoring and diagnosis system only for reciprocating compressor including inner pressure, rod position and monitoring vibration per each degree of crank angle.

Q & A

Thank you