Reliability Improvement for Reciprocating Compressor Valve in CCR Reformer

(Case study)

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1. Abstract

Background

After revamp of reformer CCR process where all three compressors are running without stand-by, compressor valve life decreased drastically from 1 year to a few(2~3) months.

Troubleshooting

Whole entire factors were investigated from process condition change, piping layout, separating drum size and valve design.

Very viscous and sticky heavy hydrocarbon called `Green Oil' was found at the valves & cylinder could cause valve late closing and consequential excessive impact stress during valve closing.

Increased colder spill-back by-pass flow could cool down gas after separator drum made easy formation of heavy hydrocarbon condensate.

Moreover liquid condensate could exist as slug at low point of suction manifold piping directly connected to compressor suction.

Valve dynamics and pulsation after revamp was acceptable but plate type valve seemed to be not good choice under service including sticky liquid showing bouncing at edge of plate during late closing.

1. Abstract

Solution implementation and Result

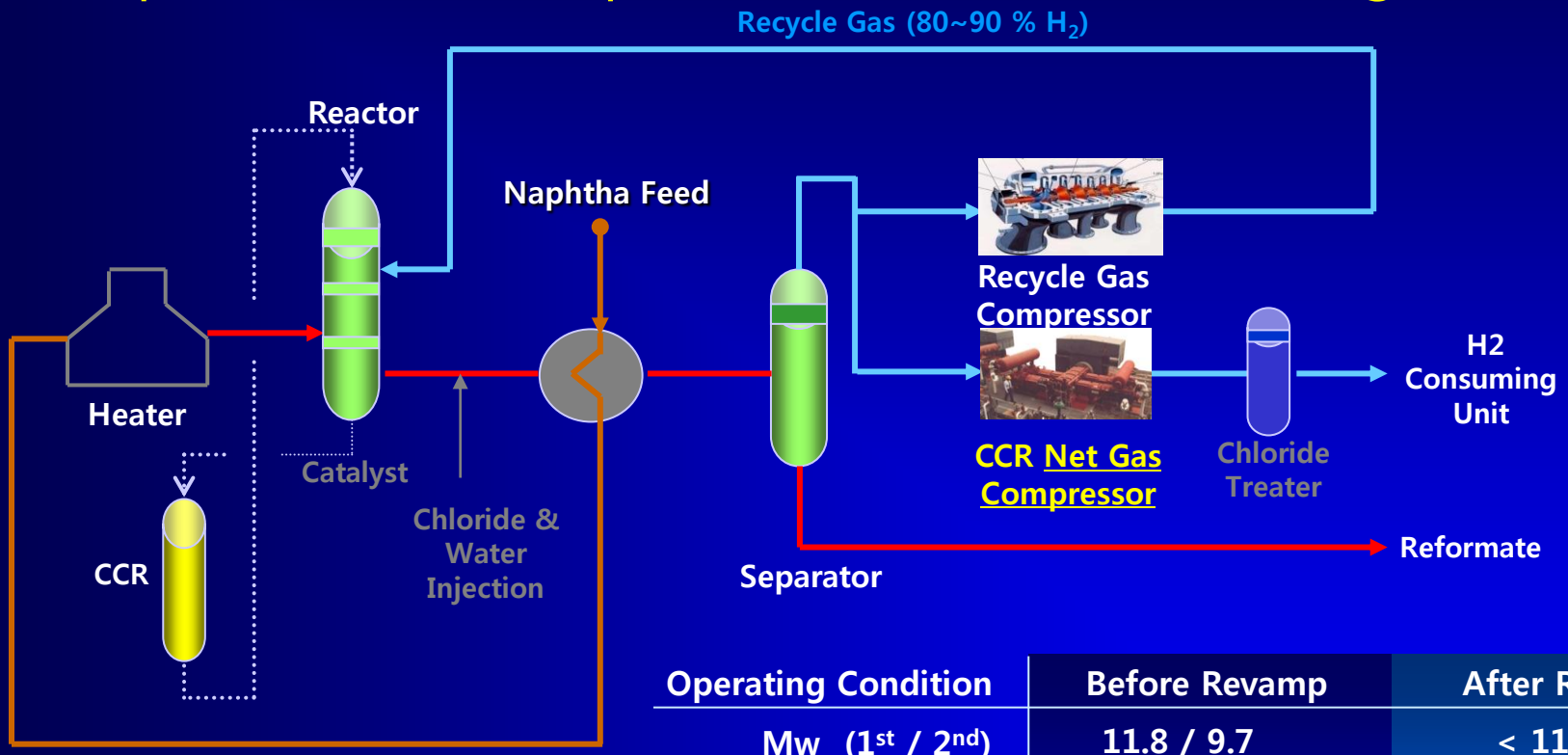
Low point drain of compressor suction manifold piping was added for liquid removal and spill-back flow was reduced by running compressors at partial load to reduce condensation by colder by-pass flow.
Valve type was changed to poppet type which is known as relatively better for very viscous and sticky liquid service.
Detail study and investigation on suction separator showed nothing bad. After all improvement implementation valve life increased to over 1 year.

Lesson Learned

This is a case study for valve failure where entire relevant factors were investigated and any failure of each parameter or its combination can reduce valve life. Mechanical engineer should have relevant knowledge(from mechanical even more to process) and capability to organize the knowledge even process to find root cause.

2. Problem faced

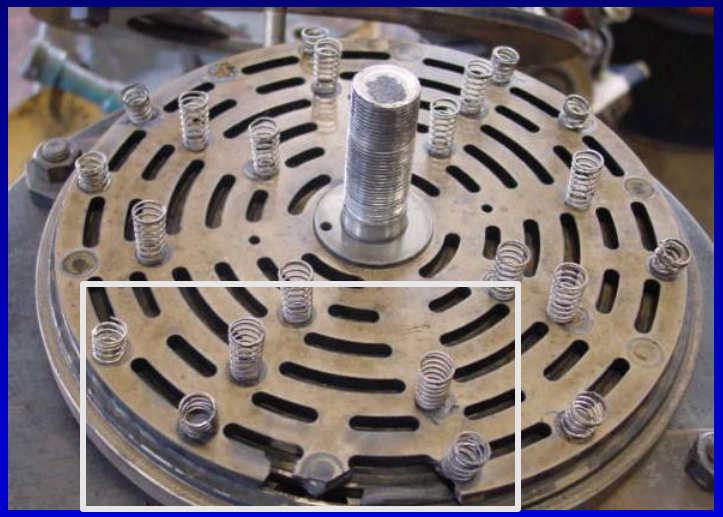
Reformer process was revamped where all three net gas compressor run and process condition are changed



Operating Condition	Before Revamp	After Revamp
Mw (1st / 2nd)	11.8 / 9.7	< 11.6 / 8.5
Suction Temp. (1st /2nd)	40 / 38	49~52 / 38
Pressure Ratio (1st /2nd)	2.38 / 2.78	3.14 / 2.83
Net Gas Compressor at Operating	2 out of 3	3 run out of 3

2. Problem faced

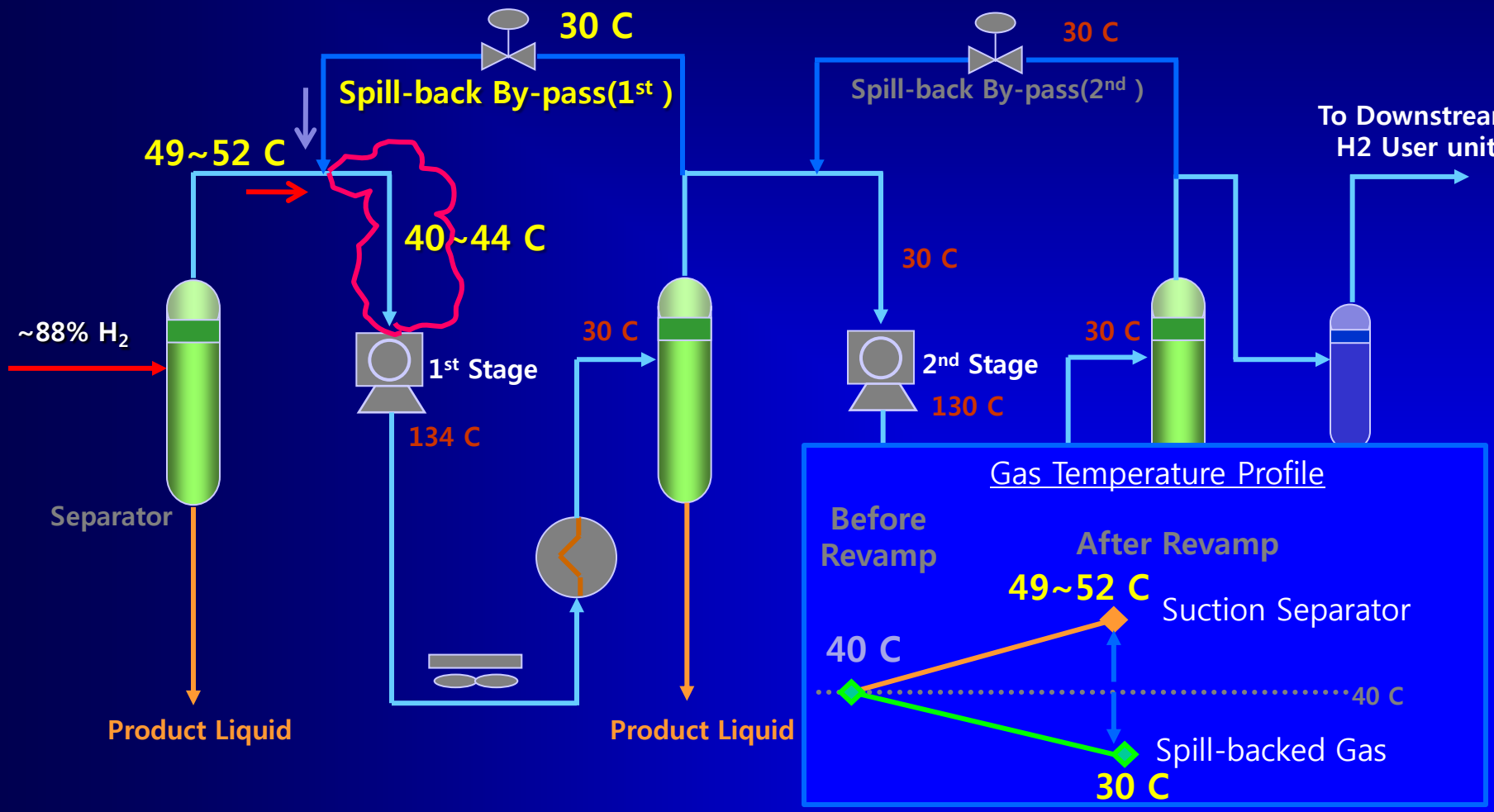
1st stage discharge valve failed every 3 months after the revamp. Sticky hydrocarbon deposit on the valve and large amount liquid found in the cylinder



- ✓ **Heavy Hydrocarbon Deposit**
  : Liquid phase at running
- ✓ **PEEK Plate / Spring Failed**
  - **Typically edge of valve plate failed with its springs**

3. Root Cause failure Analysis

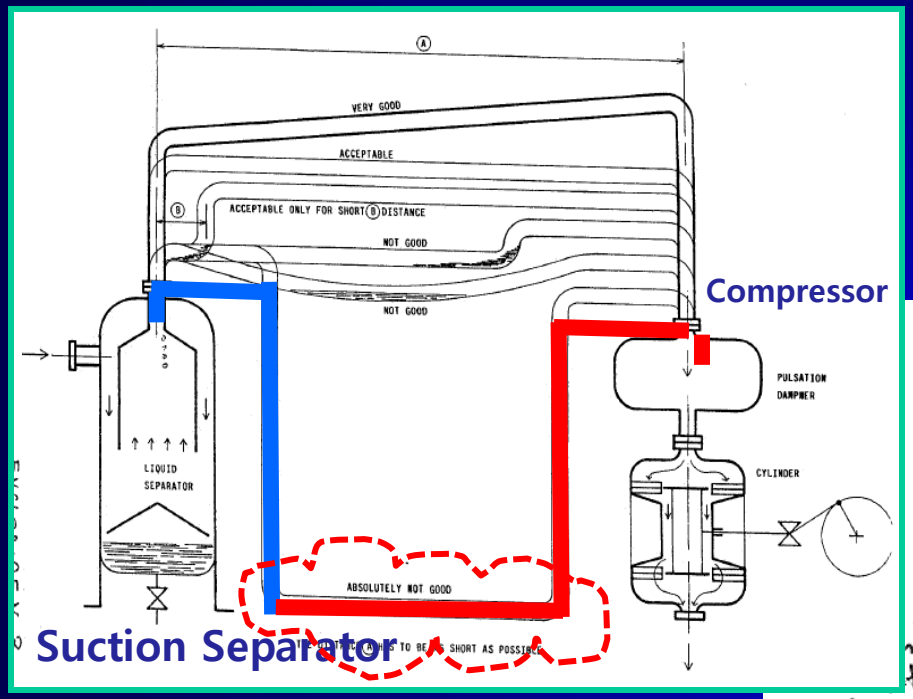
Cooled spill-backed gas seems to condense suction gas because of temperature difference after revamp



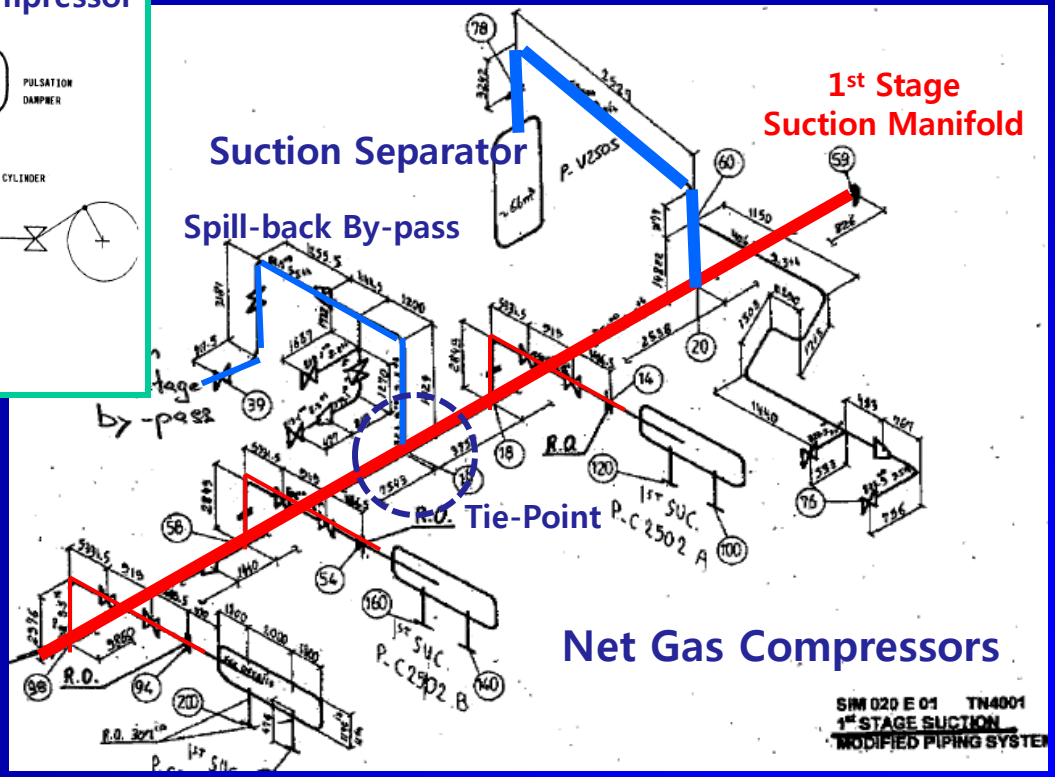
※ *Area where gas seemed to condense (Cloud Mark)*

3. Root Cause failure Analysis

Condensed liquid will be collected at suction manifold piping and can be ingressed to compressor suction as liquid slug because of its layout



ISO Drawing (1st Suction)



3. Root Cause failure Analysis

Liquid phase hydrocarbon is very viscous and sticky which is composed of inherent process reaction

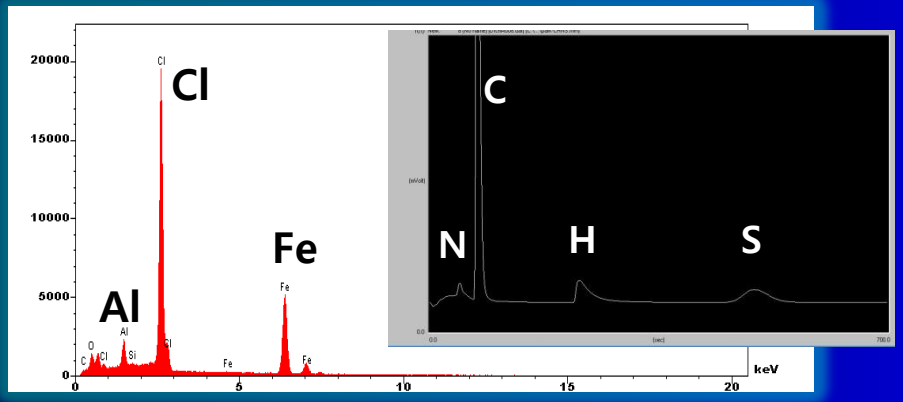
Green Oil (Typically generated at CCR) — $\underline{NH_4Cl} = NH_3 + HCl$

Condensed H/C — **C17~ C20 Hydrocarbon**

Corroded — $FeCl_2 + H_2 = Fe + HCl$

Catalyst — Al_2O_3

EDX / EA Result (Deposit)



Component found

Cl, Fe, Al, N, Si, C, H

N (0.9~3.7%)

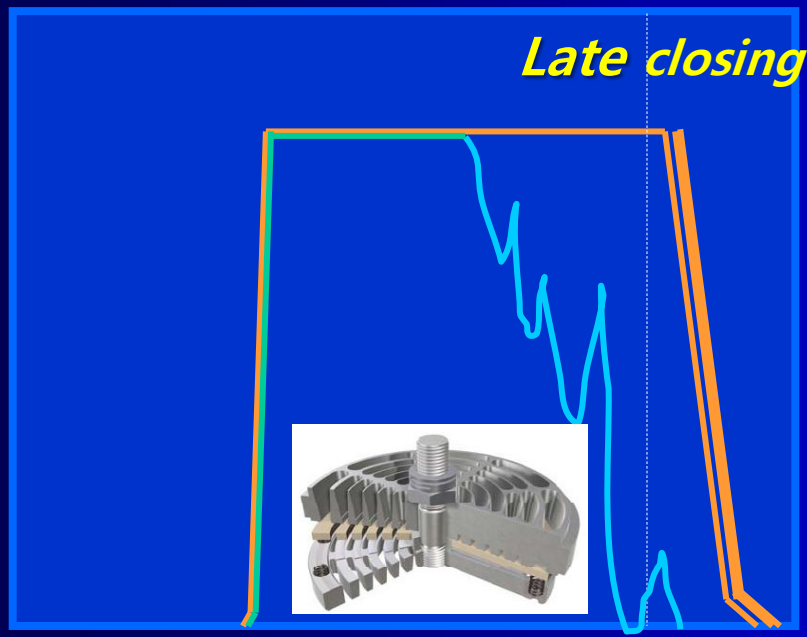
$\underline{NH_4Cl}$, $FeCl_2$, Al_2O_3

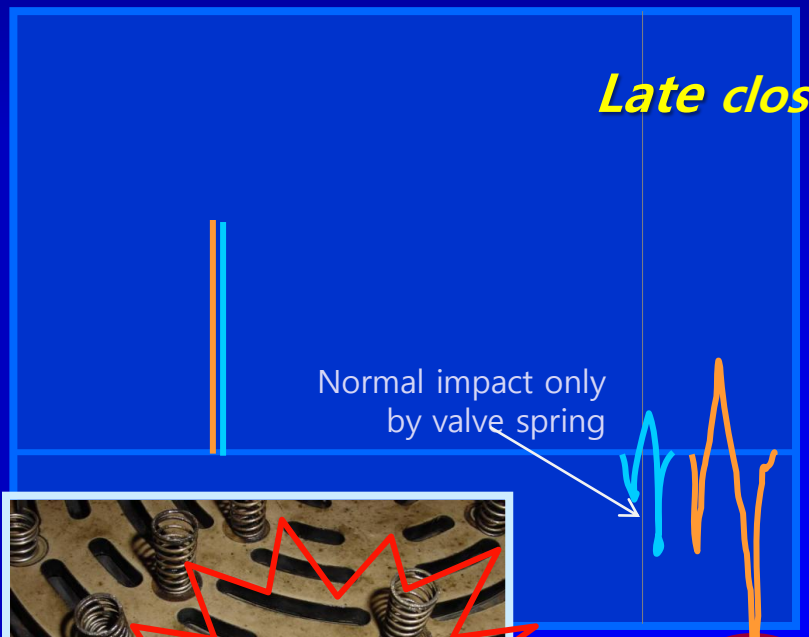
3. Root Cause failure Analysis

Valve late closing caused by sticky liquid(sticktion) seem to cause excessive valve impact consequently during valve closing by gas flow

Liquid slug could slam the valve and seemed cause excessive stress on the plate & spring

Valve Dynamics Diagram (@ Late Closing)





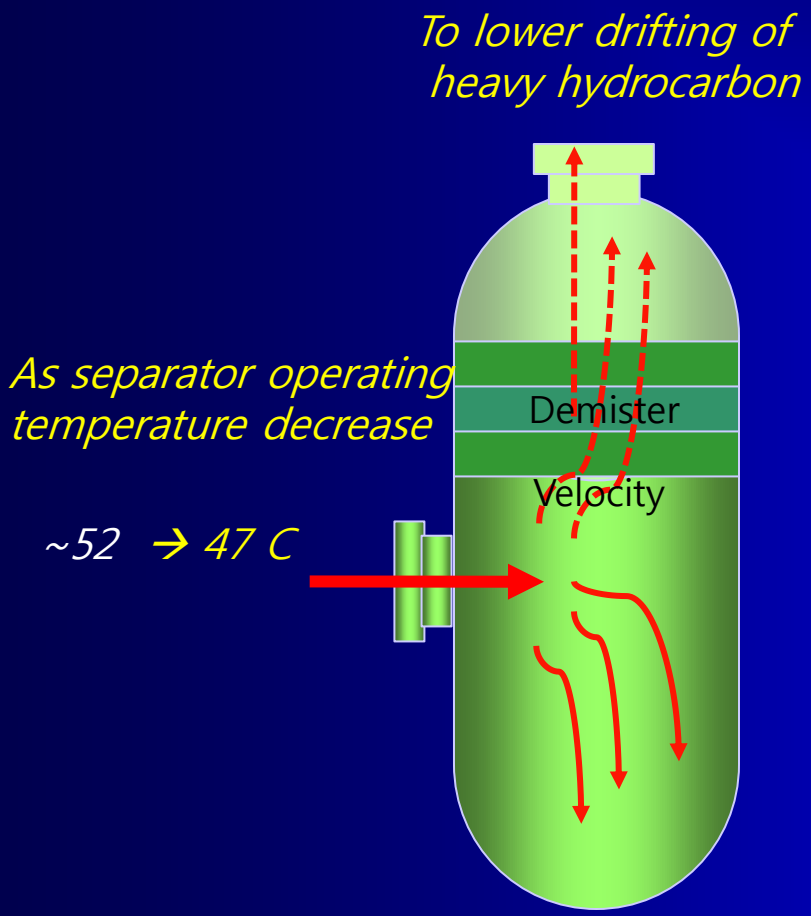
4. Solution Provided and its Result

Solution to reduce formation of sticky liquid and to remove it effectively is provided (phased as I & II)

Possible Cause	Solution	Implementation Phase
✓ Heavy H/C condensed because it is cooled down by spill-backed gas	① To decrease 1st suction temp. to minimize carry-over of heavy hydrocarbon(49~52 → ~47 C)	Phase I
	② To reduce spill-back flow by partial load operation (two compressor run at 75%)	
	③ To add continuous drain trap at suction manifold piping and make slope of manifold	
	④ To Change spill-back tie point for preventing condensing	Phase II

4. Solution Provided and its Result

① To Decrease Suction gas temperature decreased as low as possible to expect minimize of heavy hydrocarbon carry-over



✓ To minimize drift of heavy hydrocarbon through separator demister as to lower operating temperature

✓ Separator drum size and state

: drum size is properly designed

Stage	Actual Velocity	Allowable Velocity
1st	1.3	< 2.3
2nd	0.4	< 1.7

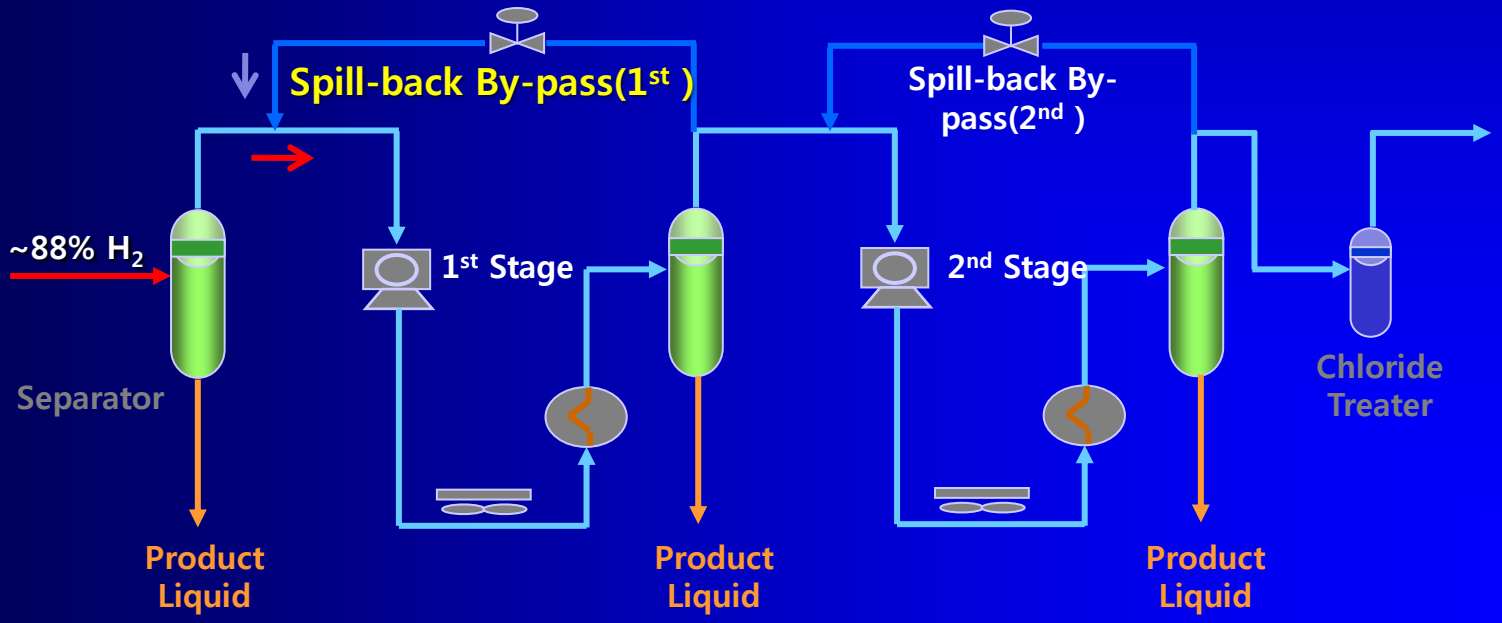
: Drum demister was investigated and found not damaged

4. Solution Provided and its Result

② To reduce spill-back flow by partial load operation (two compressor run at 75%)

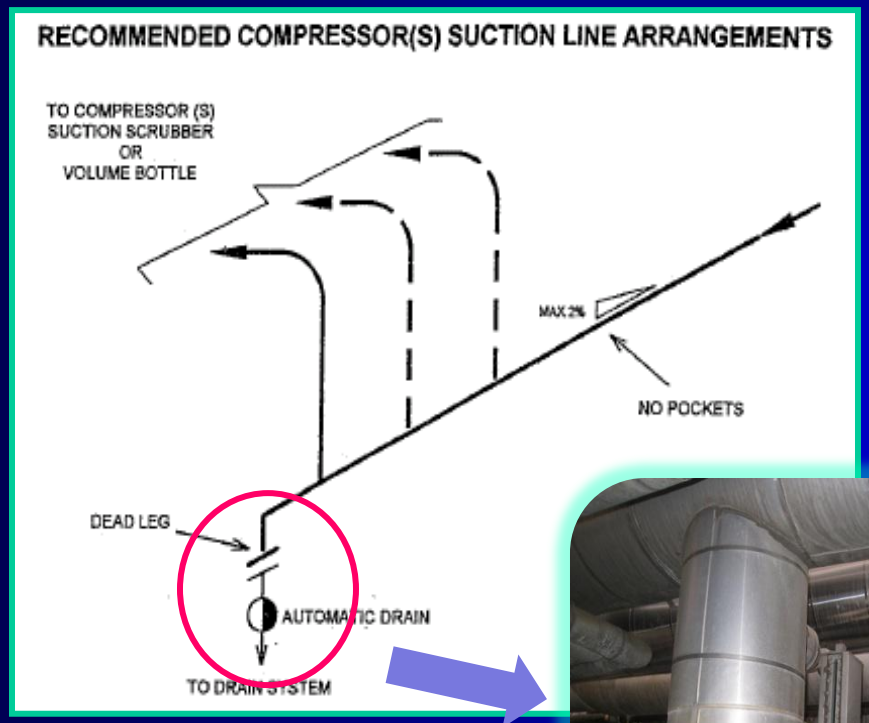
Stage	Before Improve	After Improve
Load	100 /100/100%(36,798 Nm^3/Hr) (29 % spill-backed)	100 /**75/75%** (15 % spill-backed)

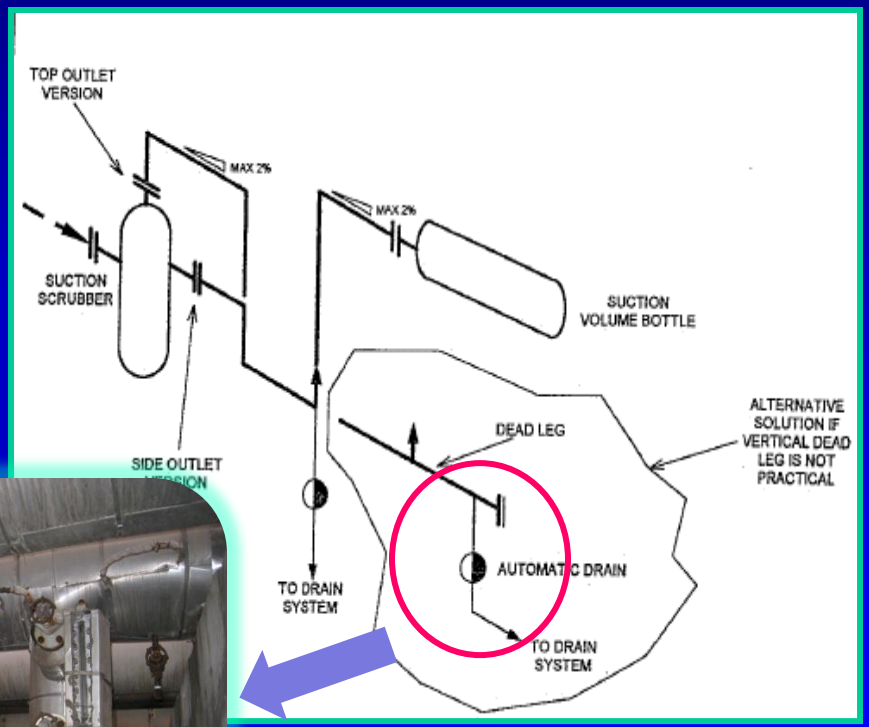
Reducing inlet flow condensing by reduced cold spill-back flow makes expected to give positive effect influence to compressor valve



4. Solution Provided and its Result

③ Drain traps were added at end point of suction manifold to prevent accumulation of condensed liquid and let manifold piping sloped to ease collection to trap

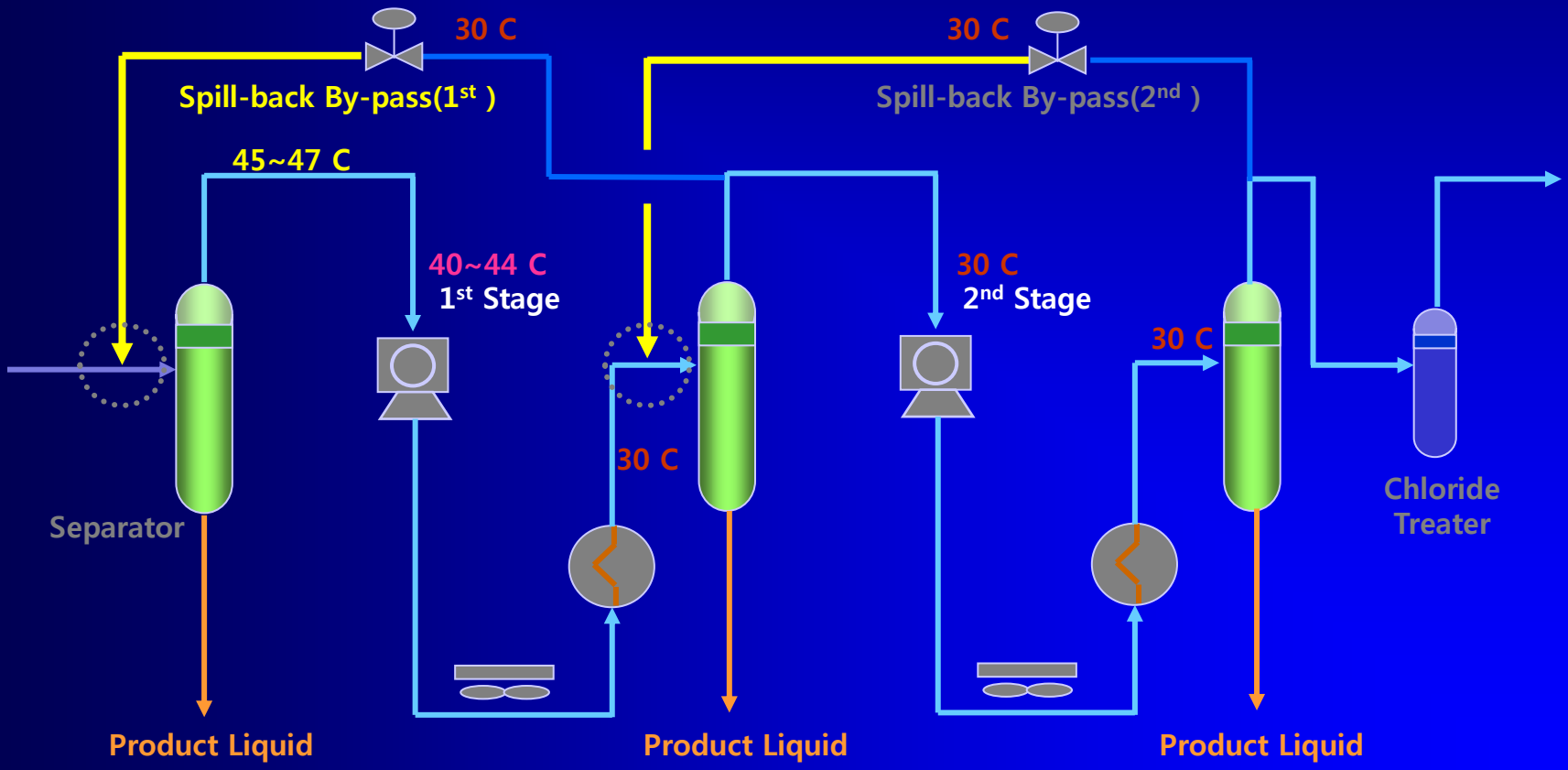




4. Solution Provided and its Result

④ To Change spill-back tie point for preventing condensing (Compressor inlet → Separator)

Due to high investment cost to modify piping layout and suction drum, it was decided to apply the option as phase II.



4. Solution Provided and its Result

⑤ Solution to minimize late closing influence of valve is provided by changing valve type

Possible Cause	Solution	Implementation Phase
✓Excessive valve impact stress by late closing at a presence of sticky hydrocarbon	⑤ To change valve type from plate to "poppet" valve to minimize sticktion	Phase I

Type	Plate	Poppet
Shape		
Remark	- Widely Used (Economical) - Bounced at edge area at late closing by sticky liquid	- Better at sticktion (from a inherent structure) - Wear at edge of poppet - Recently widely used and life proven for CCR

4. Solution Provided and its Result(Consolidated)

After application of the solution provided, valve life increased more than 1 year

Phase	Improvement Idea	Implementation			Result (Valve Life)
		Yr1	Yr2	Yr3 ~	
I	① Decrease suction temperature	○			④+⑥: **12 Months**
	③ Add continuous drain trap at suction manifold	O			
	⑤ Change valve type to "poppet"	O			
	② Reduce spill-back flow (by Partial Load operation)		O		④+⑥+⑤+②: **>16 Months**
	Clean suction piping system during turnaround		O		
II	④ Change spill-back tie point for preventing condensing (Compressor inlet → Separator)			X	Due to high cost (As Phase II)

5. Lesson Learned

- ✓ Valve life is a very complicated result caused not only by mechanical origin but also process(all system matter).
- ✓ Negative influence of process condition on compressor valve life is very important in this case
  Changed process condition made easy formation of sticky liquid and more influence to compressor valve
- ✓ In addition, process piping scheme can also short valve life by admitting liquid drain to compressor
- ✓ In case where process gas contain viscous and sticky liquid, good engineered "poppet" type valve also can be a good candidate for life extension over plate type valve

END of Document

Appdx. Specification of Net Gas Compressor

❖ **CCR Net Gas Compressor:**

Compressor provide net hydrogen gas(> 85 %) from CCR to downstream H2 consuming plants

❖ **Summarized information of Net Gas Compressor**

- Installed: since 1989
- Type : 2 Stages / 4 Cylinder (2 Cylinder per each stage)
  Double Opposed Horizontal Reciprocating Compressor
  Lubrication Type
- Capacity: 36,798 Nm3/Hr
- Pressure: 2.7(1^{st} stage suction) → 25.7 kg/cm^2G(2^{nd} stage Discharge)
- Motor : 3960 kW / 300 RPM

Appdx. Root Cause Analysis Table

Type	Possible Cause		Possibility
Process	✓ **Influence of Liquid**	▪ Heavy H/C condensed because of temperature difference between separator and spill-back gas	●
		▪ liquid could carry over from accumulated at low point of suction manifold	●
		▪ Cylinder jacket cooling water temperature lower than suction gas temperature (44C < 49~52C)	×
		▪ Size of suction separator and state of its demister	×
	✓ **Excessive lubricant**	▪ Excessive lubricant injected over vendor recommendation (Just above recommendation)	×

Appdx. Root Cause Analysis Table

Type	Possible Cause		Possibility
Mechanical	✓ **Valve material**	▪ Spring material was suitable for the gas (Co-Based Alloy)	×
		▪ PEEK(plate) proven for the gas and similar service	×
	✓ **Valve Design**	▪ Valve dynamics report shows no significant problem at design (impact velocity, close angle..)	×
	✓ **Valve Type**	▪ Plate type valve itself is not problem. However, plate type valve is more apt to close late by sticktion	○ *
	✓ **Gas Pulsation**	▪ Pulsation study satisfied API 618 Code requirement	×

* It is evidently NOT a root cause. However if it is improved to other type valve less apt to sticktion, it will withstand longer service life even at presence of sticky liquid.