43rd Turbomachinery
30th Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
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RELIABILITY IMPROVEMENT OF MAGNETIC DRIVE PUMP FOR SPECIAL SERVICES

SK innovation

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TEXAS A&M ENGINEERING EXPERIMENT STATION

Presentation Overview

1. Executive Summary

2. Application of magnetic drive pump

3. Troubleshooting & Solution
   - 2.1 Molten Sulfur Service
   - 2.2 Ammonia Service
   - 2.3 Dirty & Weak Acid Service

4. Lesson Learned

1. Executive Summary

We, SKI, had used successfully the sealless pumps such as magnetic drive pump and canned motor pump in order to meet the environmental regulation for clean service. Based on successful experiences for many years, magnetic drive pumps have been aggressively applied to improve the seal life for special services such as sulfur, caustic, ammonia, etc since 2005. The magnetic drive pump has been preferred because of various advantages (easy maintenance, robust design, leak free, etc).

However, we have faced important and didactic issues due to inappropriate operating procedures, protection systems and design. Unless the application and operation are taken into a consideration for special services like as molten sulfur and ammonia, the consequences of pump failure could result in devastating damage to pump parts and even fire. This case study will show how the bad actors were improved, lessons learned and guidelines for reliable operation.

Users are reluctant to apply protection systems fully compliant with API685 or vendor recommendations for non-hazardous services based on economic considerations. But they should consider providing minimum protection systems for special services, if not for all pumps.

2. Application of Magnetic Drive Pump

1) General Recommendation

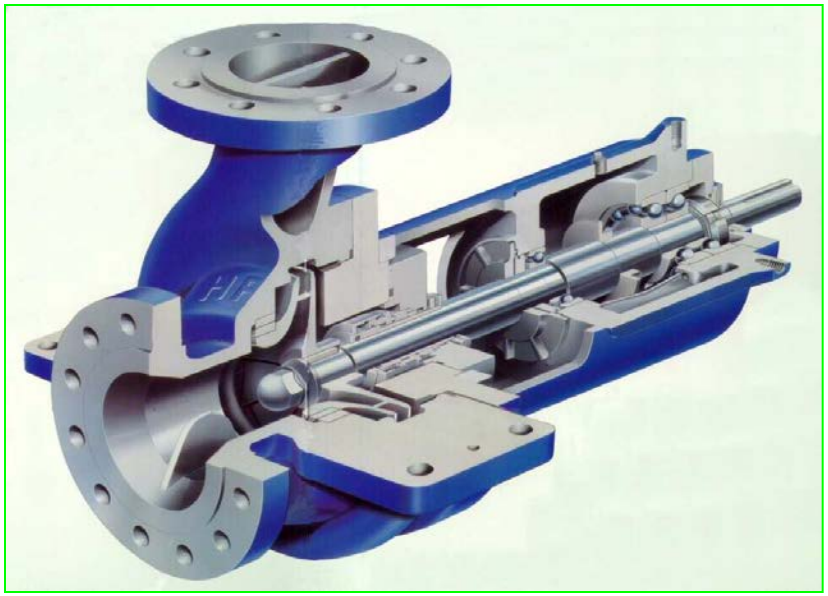
A. Acids or other liquids which cannot be allowed to leak to the environment

B. Where a mechanical seal would be expensive to buy and expensive to maintain

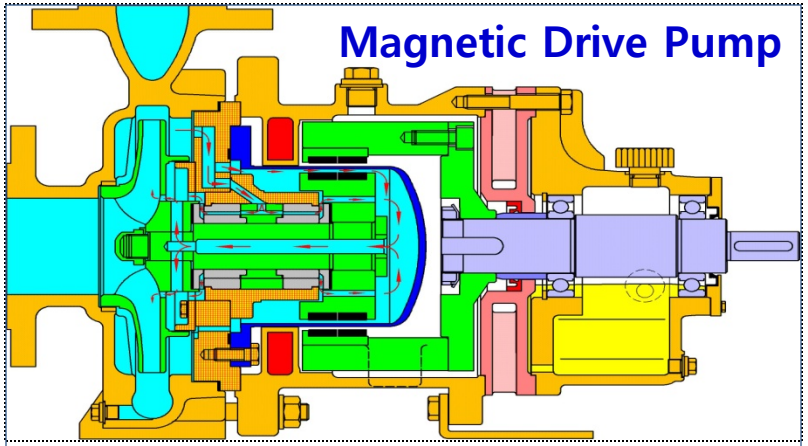
※ Advantage

- Simple, modular construction for ease of maintenance
- Leak free, seal-less construction

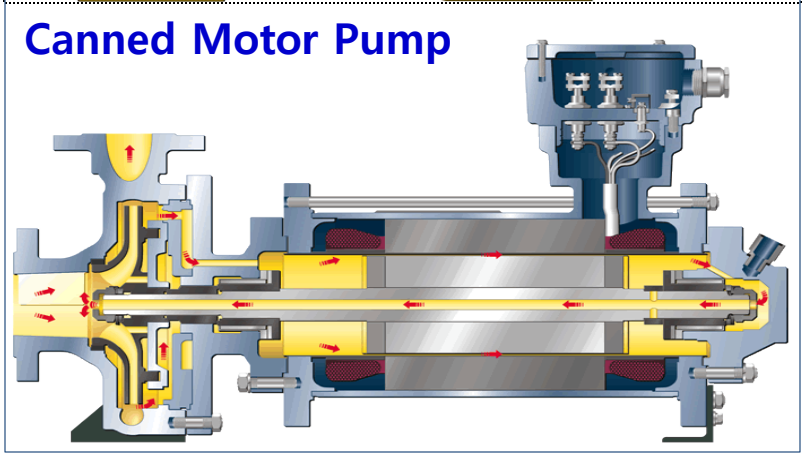
Conventional Seal Pump



Magnetic Drive Pump



Canned Motor Pump



2. Application of Magnetic Drive Pump

2) Successful Application for General Service

- Clean Service For Petrochemical Process
  - Benzene, Toluene, Xylene, etc.

- Strong Sulfuric Acid
  - 98%wt H2SO4 Acid

- Caustic Water

Environment & Safety	Maintenance
▪ "ZERO" Leakage !! ⇒ Clean !! ▪ Mitigating Risk !! ⇒ Safe !!	▪ Improved MTBF - 2~3 yrs → more than 5 yrs ▪ Saving Maintenance Cost

2. Application of Magnetic Drive Pump

3) SK Criteria

A. Pumps which dual seal should be applied for ***VOC Service, Toxic or Stench service**
- Acid Service, Benzene, Toluene, Xylene, Ammonia, etc

B. Bad Actors due to Mechanical Seal leakage
- Molten Sulfur, Caustic, Hot Oil, etc

C. Seal Pumps less than BHP 50 kW and clean service (without particle)
- Considering a capital and maintenance cost with comparing to seal pumps

D. Restricted application of Sealless Pump
- Sludges, Slurries, or Solids-laden fluids are processed.
- Possible dry running operation
- Intermittent operation

* VOC : Volatile Organic Compound

2. Application of Magnetic Drive Pump

We have applied aggressively a magnetic pump to special services.

Bad Actors in Special Service

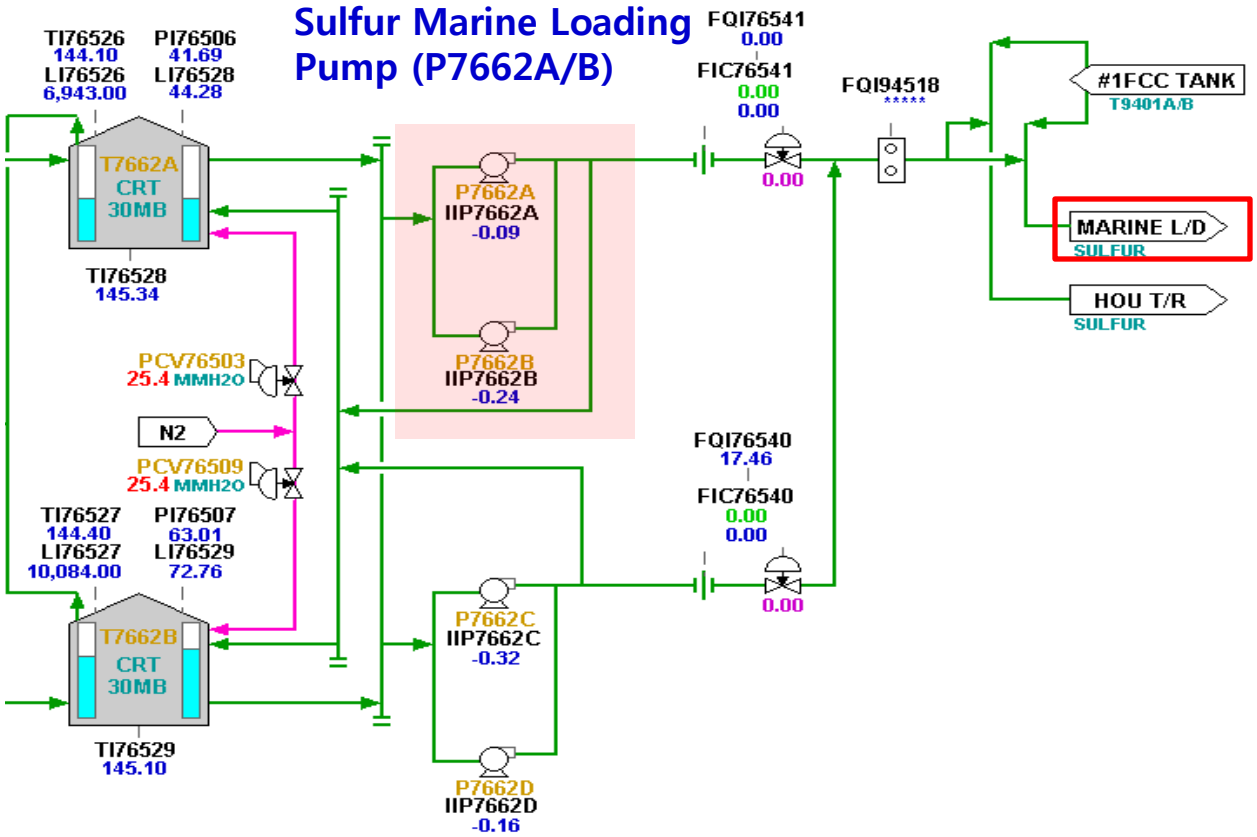
Molten Sulfur	Ammonia	Weak Acid, etc.

What is the results ?

1) Sulfur Marine Loading Pump

A. System & Specification of Pump

These pumps supply the molten sulfur from tanks to piers for marine loading.

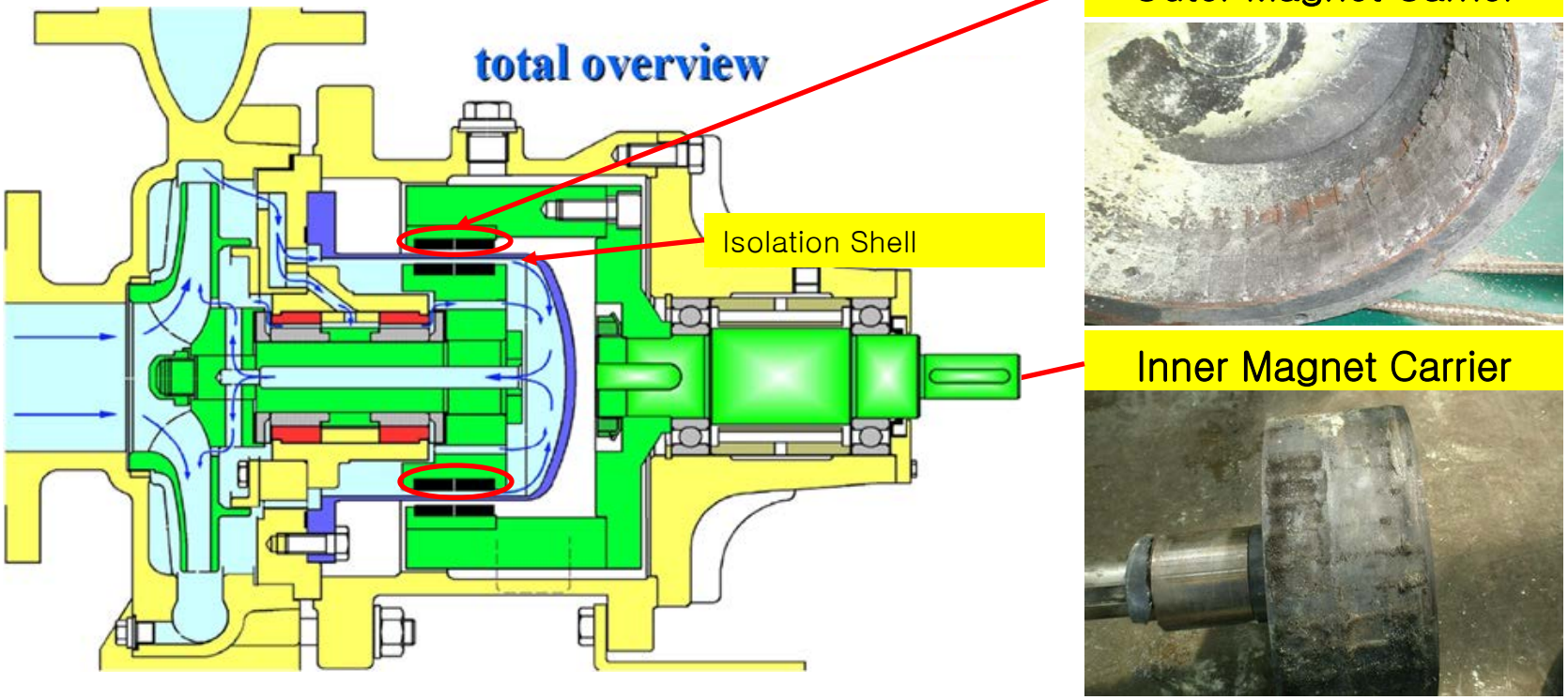


Descript.	Spec.
Service	Molten Sulfur
Temp.	138 ℃
S.G	1.79
Head	71 m
Flow	163+20 m3/hr
BHP	108.3 kW
Motor	132kW
RPM	1800

1) Sulfur Marine Loading Pump

B. Problem

- Pump shaft could not be turned by hand since pump had been operated on Aug. 14, 2010.
- Internal Parts were damaged ; Isolation Shell, Sleeve Bearing, Inner/Outer Magnet

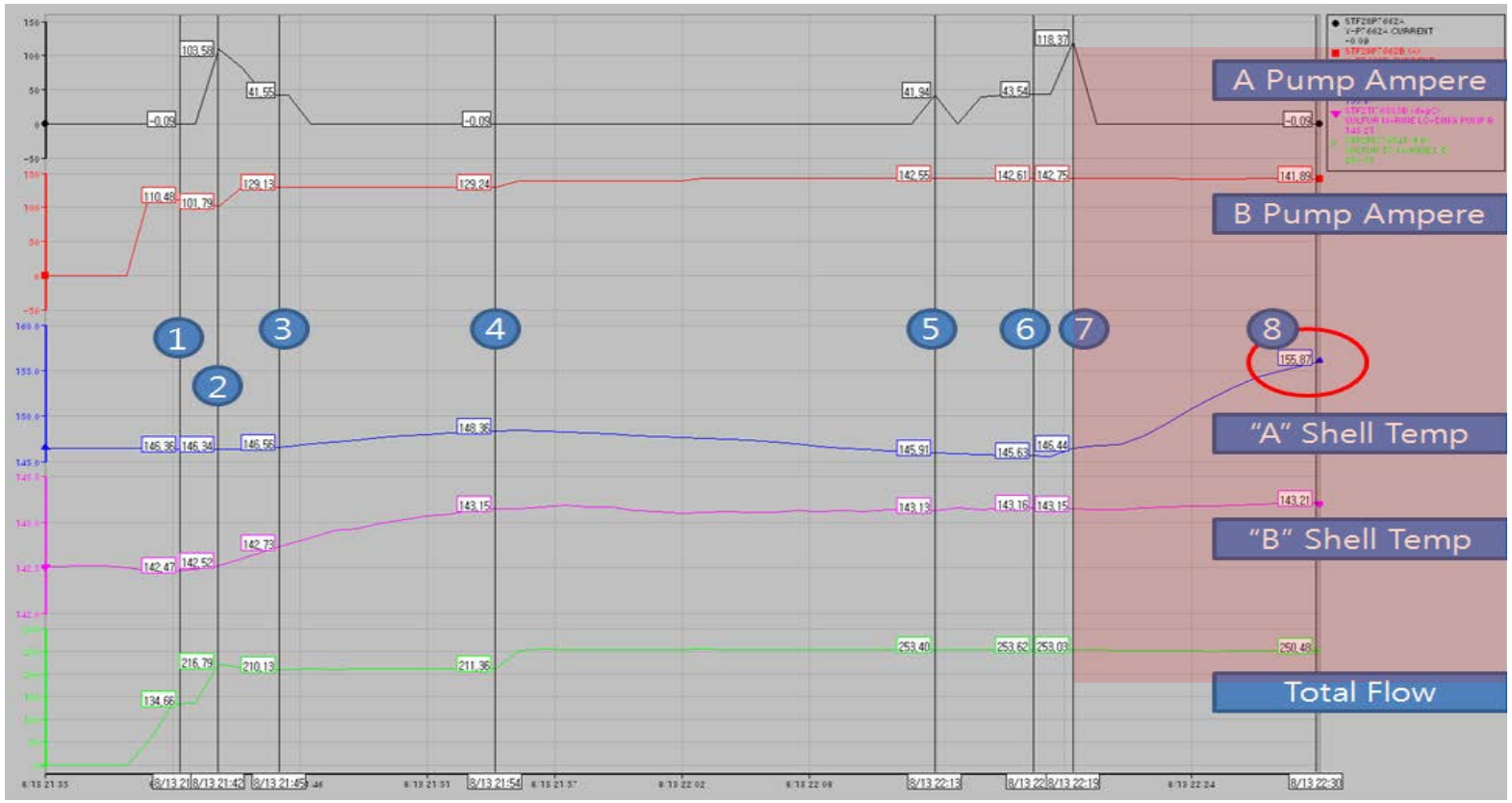


1) Sulfur Marine Loading Pump

B. Problem

Operator wanted to shorten loading time, then run two pumps in parallel.

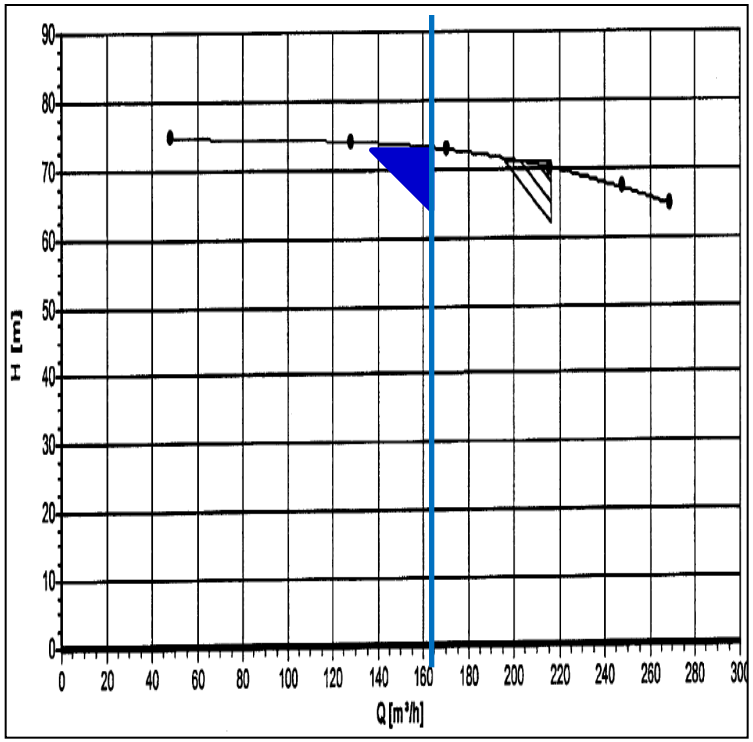
Parallel operation had been tried several times but one motor current was near no load.



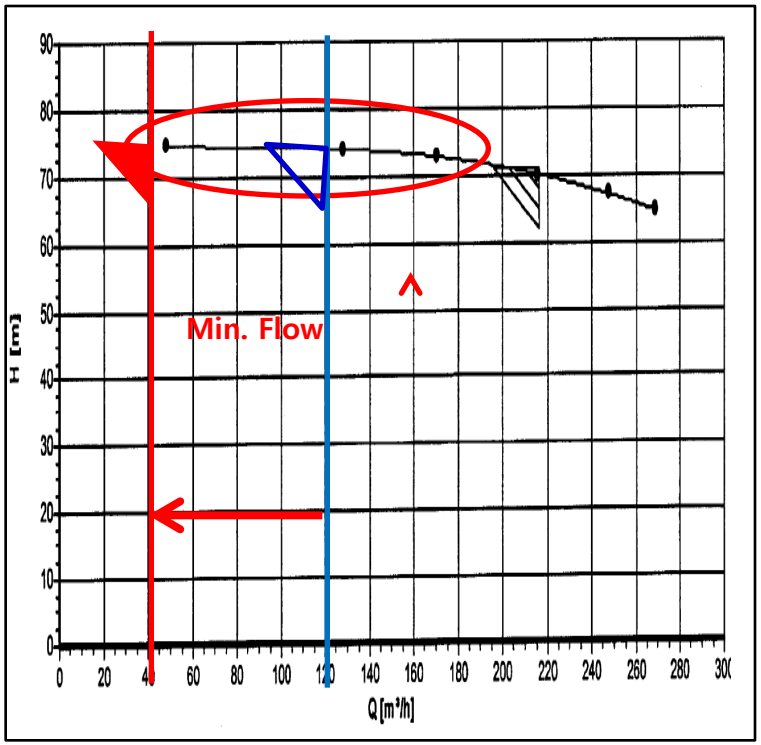
C. Troubleshooting

The parallel operation could cause unbalanced flow for each pump with flat performance curve.

Parallel operation with flat "H-Q"curve → Operation under min. flow → Excessive Heat Generation → Increasing viscosity of sulfur



"B" Pump Operating Point

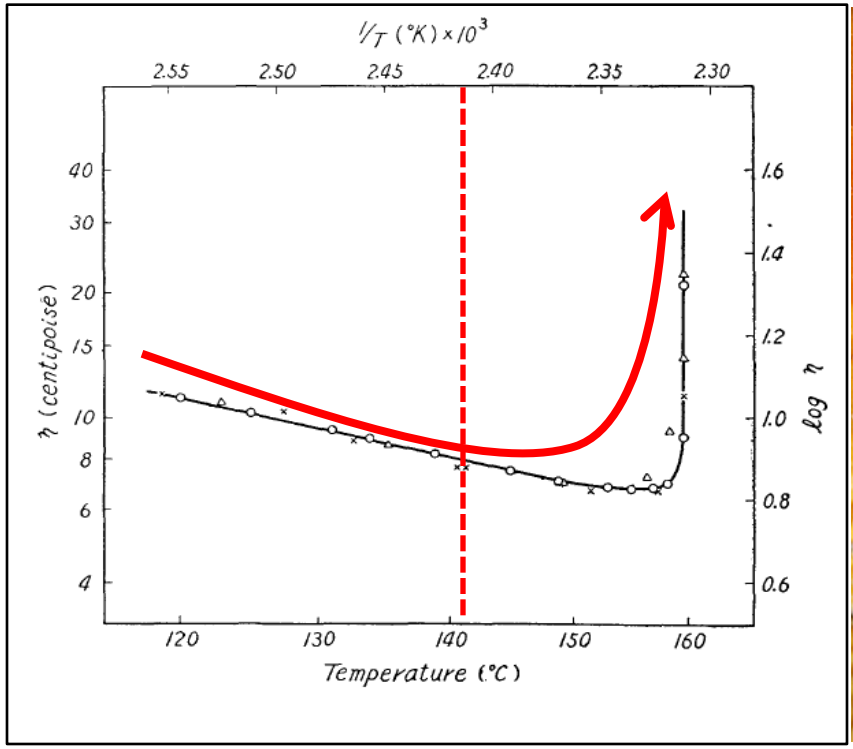


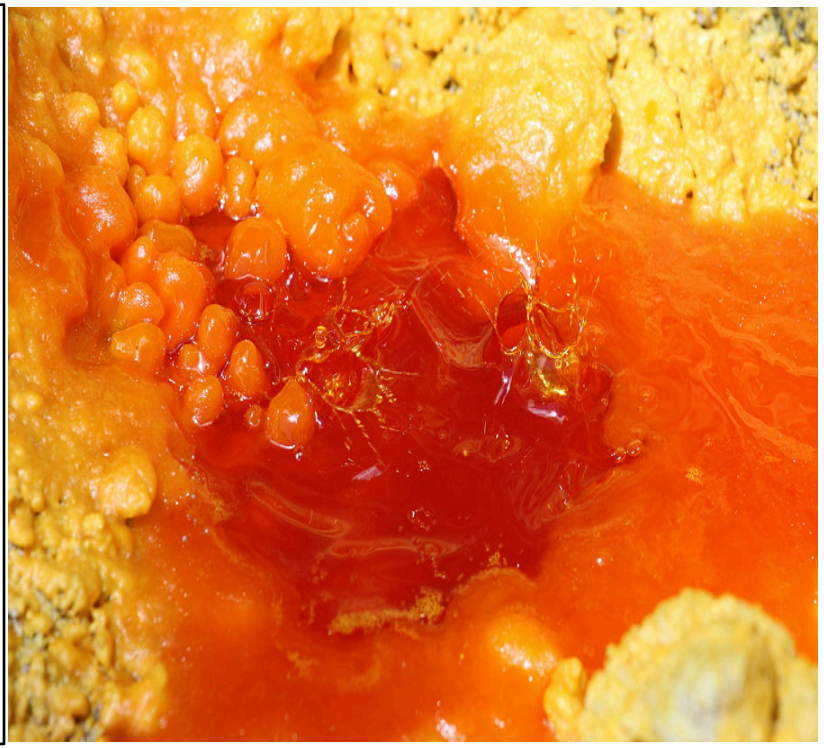
"A" Pump Operating Point

C. Troubleshooting

Heat generated due to operation under min. flow consequently increased viscosity of pumping fluid(molten sulfur).

Parallel operation with flat "H-Q"curve → **Operation under min. flow** → **Excessive Heat Generation** → **Increasing viscosity of sulfur**

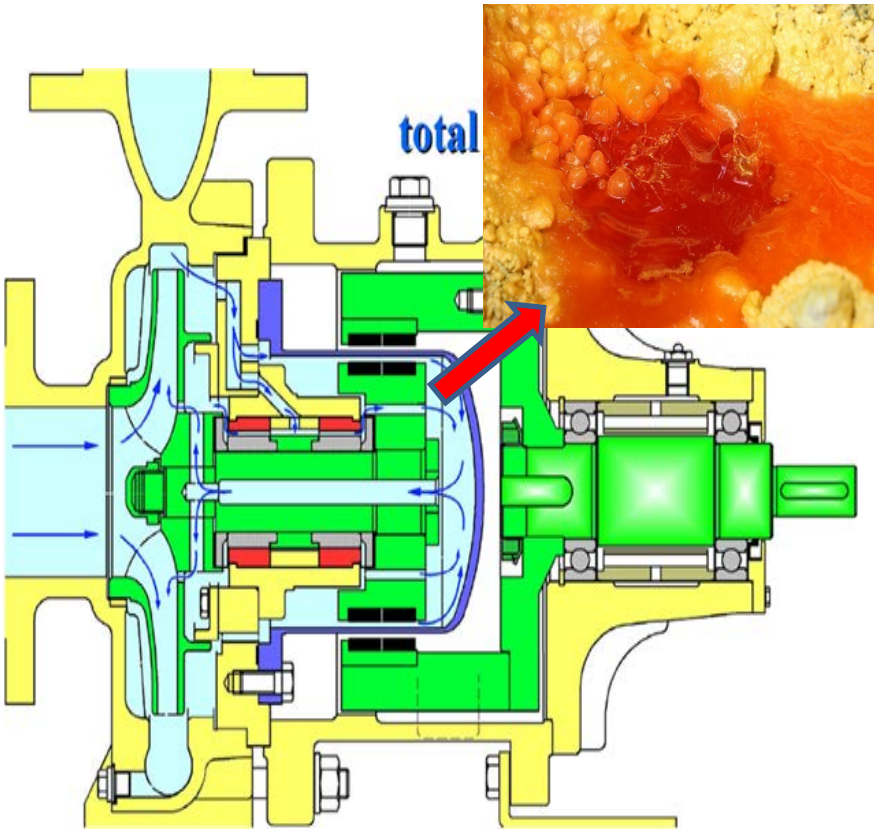


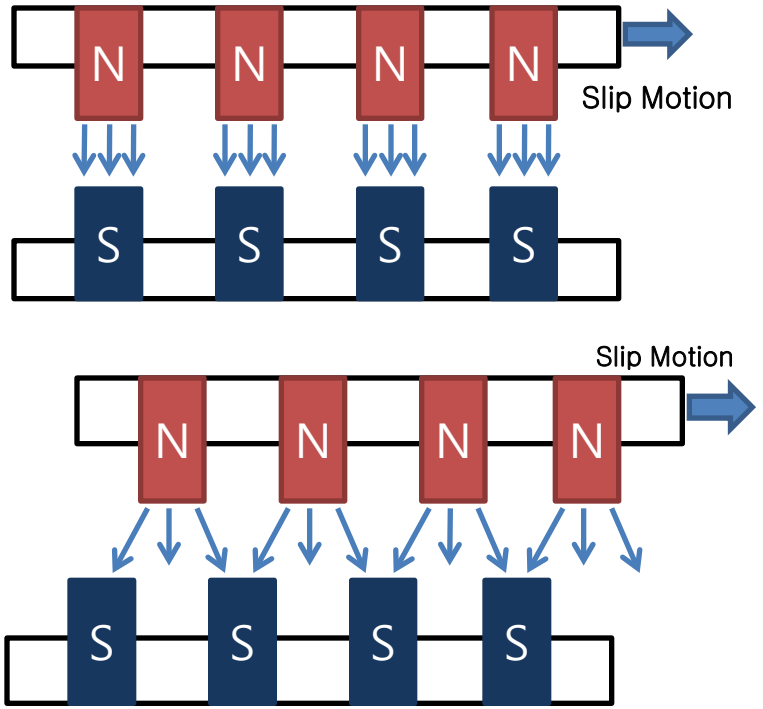


C. Troubleshooting

Solidified sulfur inside pump induced the increase of torque and finally the magnetic coupling was slipped if the coupling torque couldn't overcome it .

Torque increased → Magnetic Coupling Slip → Demagnetizing + Heat Generation → Internal Parts Damage (Coupling & Shell)

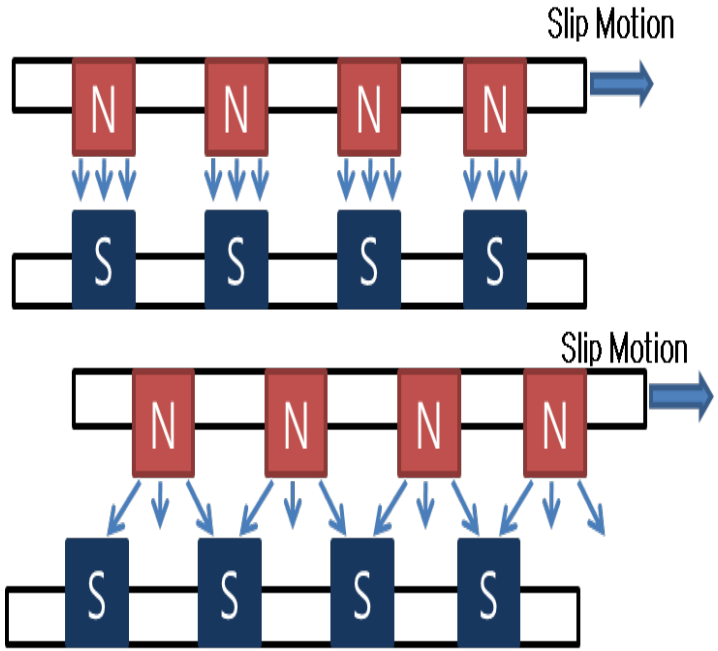


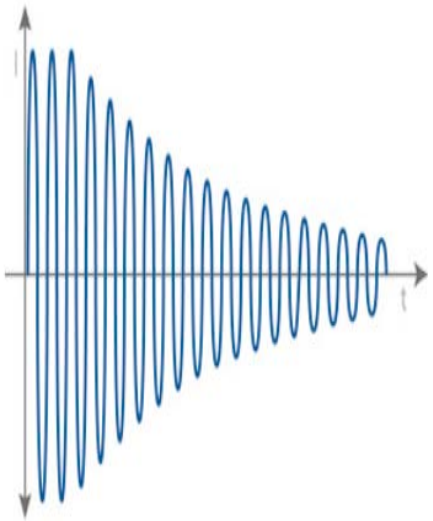


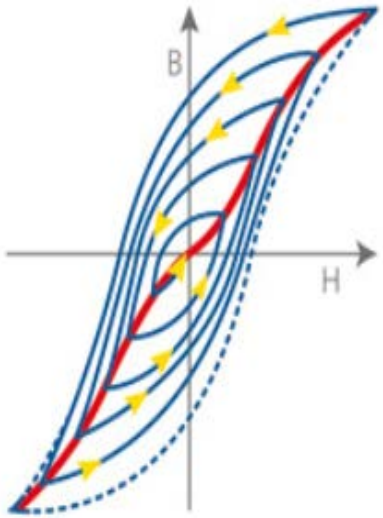
C. Troubleshooting

Torque increased → Magnetic Coupling Slip → **Demagnetizing** + Heat Generation → Internal Parts Damage (Coupling & Shell)

Slip of magnetic coupling causes alternate magnetic flux with decreasing amplitude by hysteresis loop



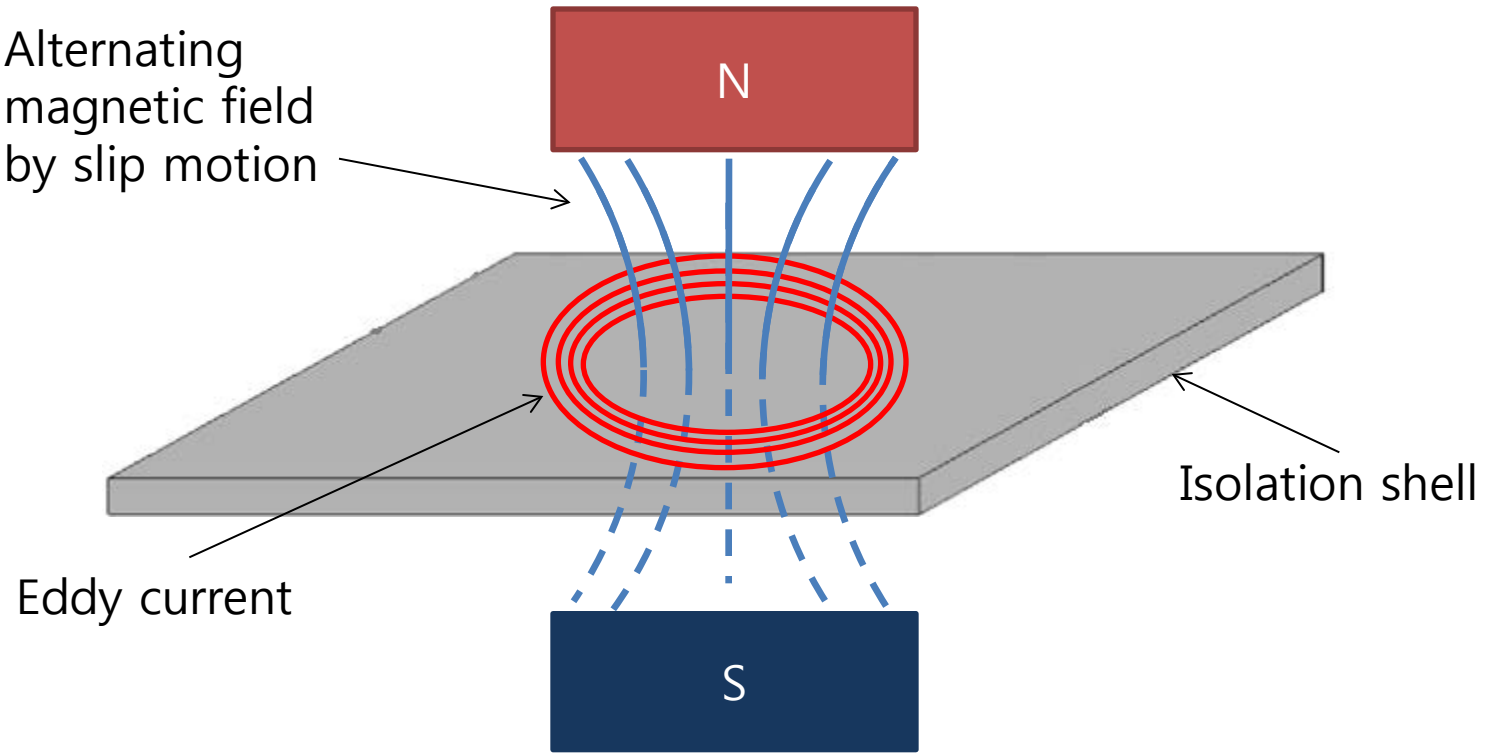




C. Troubleshooting

Torque increased → Magnetic Coupling Slip → Demagnetizing + Heat Generation → Internal Parts Damage (Coupling & Shell)

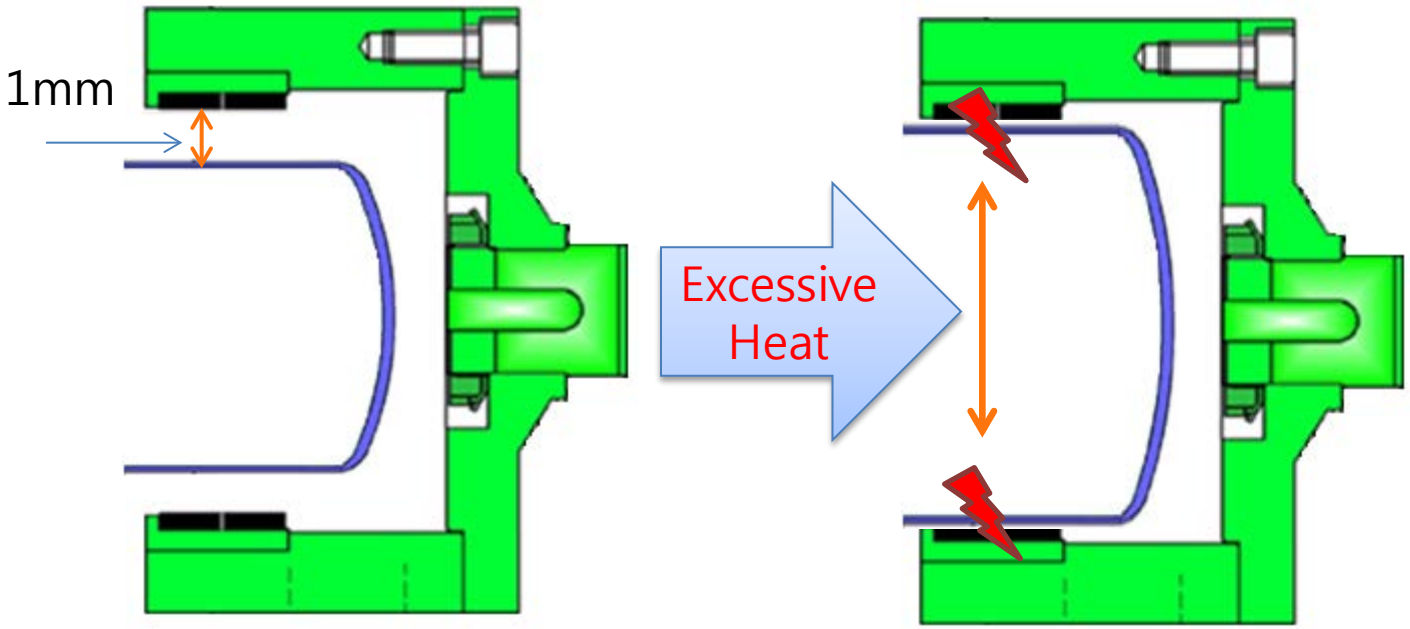
Eddy current in isolation shell inducted by alternate magnetic flux, causes excessive heat by Ohmic loss like induction furnace



C. Troubleshooting

Torque increased → Magnetic Coupling Slip → Demagnetizing + Heat Generation → Internal Parts Damage (Coupling & Shell)

Thermal expansion of isolation shell by excessive heat cause contact with outer magnet carrier



Clearance between outer magnet carrier and isolation shell is very small to prevent magnetic loss. Excessive heat can make isolation shell easy to contact to outer magnet carrier.

C. Troubleshooting

Torque increased → Magnetic Coupling Slip → Demagnetizing + Heat Generation → Internal Parts Damage (Coupling & Shell)

All major internal parts were severely damaged.

C. Troubleshooting

Problem Sequence	Phenomenal Causes	Aspect
① Operation under Minimum flow	ⓐ Parallel Operation with flat performance curve	Operation
② Consequential Influence → Excessive heat generation due to operation under minimum flow → Increase viscosity due to Excessive heat → Torque was increased higher than magnetic rated torque		
③ Magnetic Coupling Slip	ⓑ Magnetic coupling torque was less than motor trip torque	Design
④ Magnetic coupling was demagnetized	ⓒ Pump didn't stop as soon as magnetic coupling was slipped	Protection System

D. Solution Provided and its Result

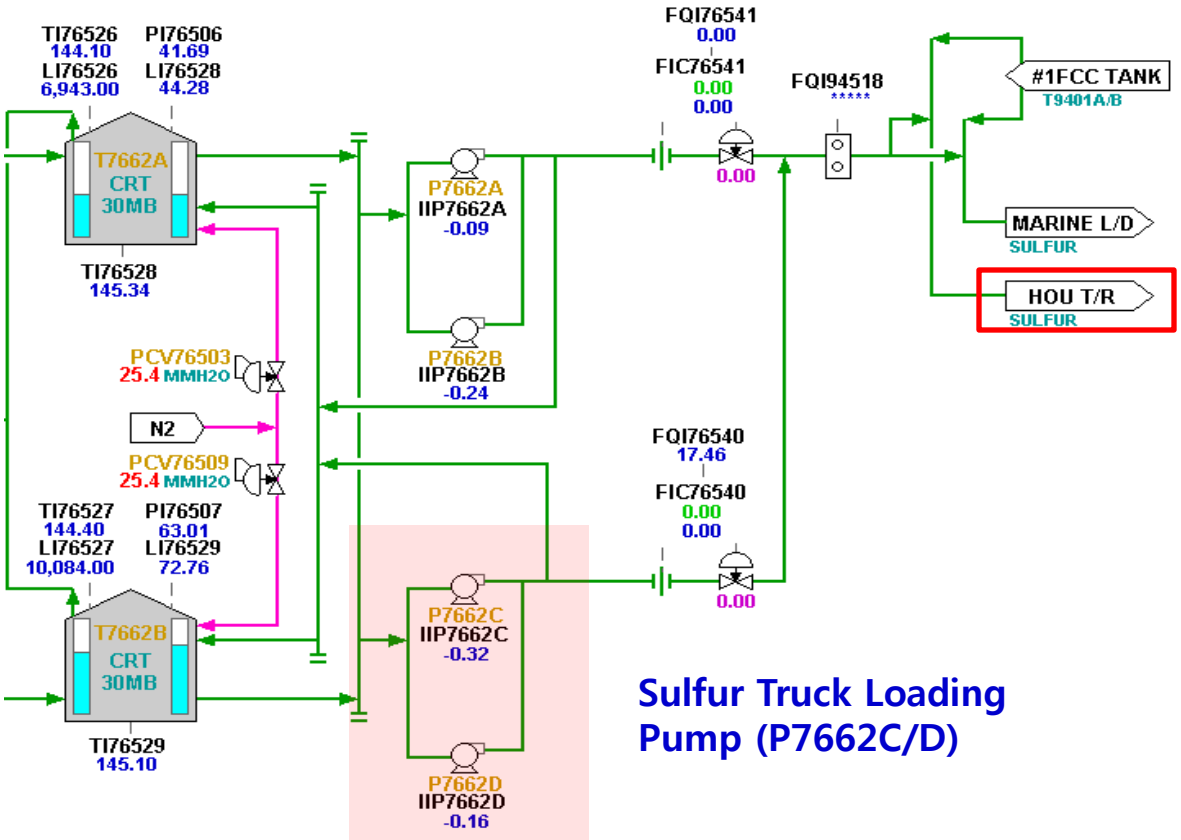
Root Causes	Solutions Provided	Aspect
ⓐ Parallel Operation	▪ Prohibit the parallel operation of pumps	Operation
ⓑ Insufficient Magnetic coupling torque	▪ Increase torque rating of magnetic coupling higher than motor's	Design
ⓒ Pump didn't stop as soon as magnetic coupling was slipped	▪ Implement proper protection system - Shell Temperature Monitoring & High Trip - Motor Amp. Low Trip for slip of Magnetic Coupling	Protection System
ⓓ Additional remedy	▪ Enlarge the size of min. flow orifice to increase min. by-pass flow	Design

These pumps have been operated stably since 2010 without any trouble

2) Sulfur Truck Loading Pump

A. System & Specification of Pump

- This pumps send the molten sulfur from tanks to loading arm for truck loading.



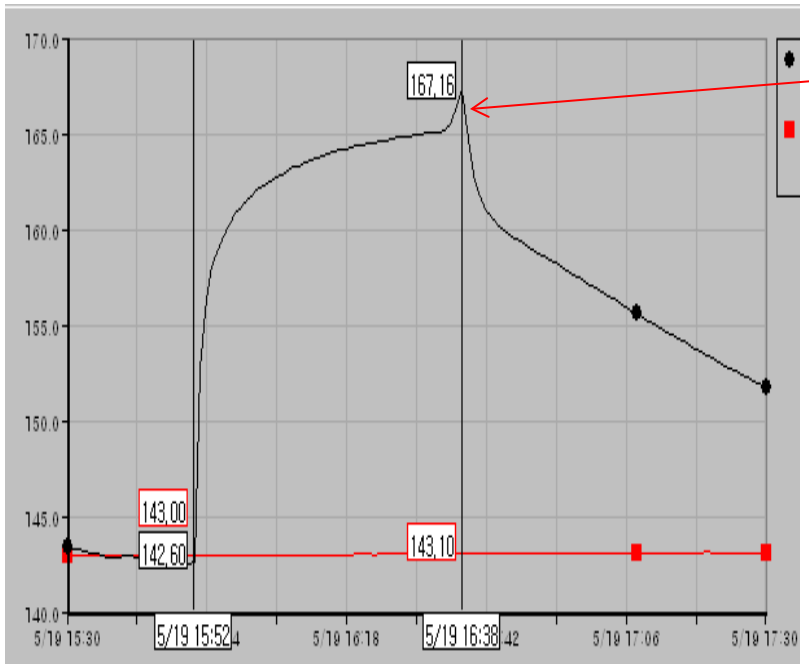
Sulfur Truck Loading Pump (P7662C/D)

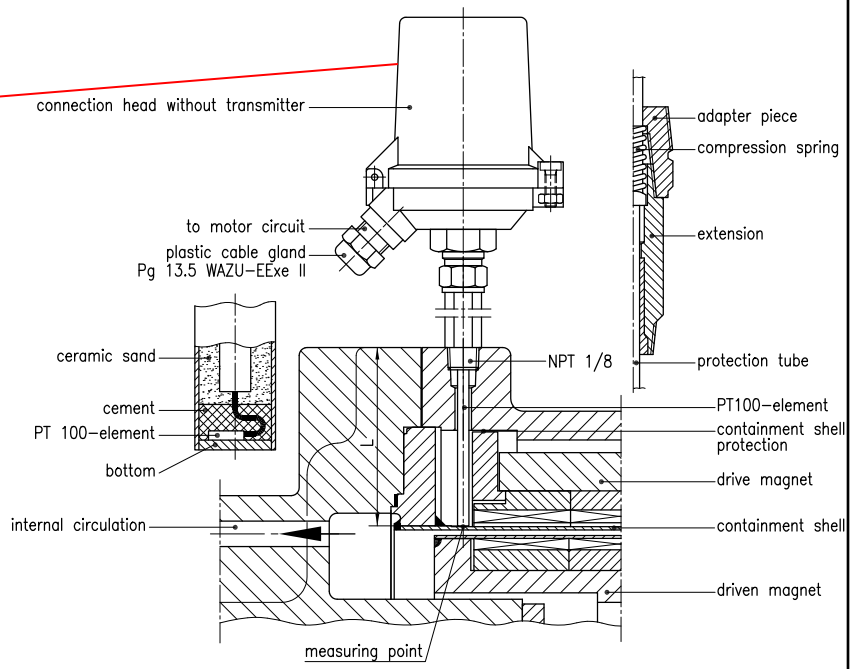
Descript.	Spec.
Service	Molten Sulfur
Temp.	138 ℃
S.G	1.79
Head	159 m
Flow	17.3+7 m3/hr
BHP	85 kW
Motor	110kW
RPM	3600

2) Sulfur Truck Loading Pump

B. Problem

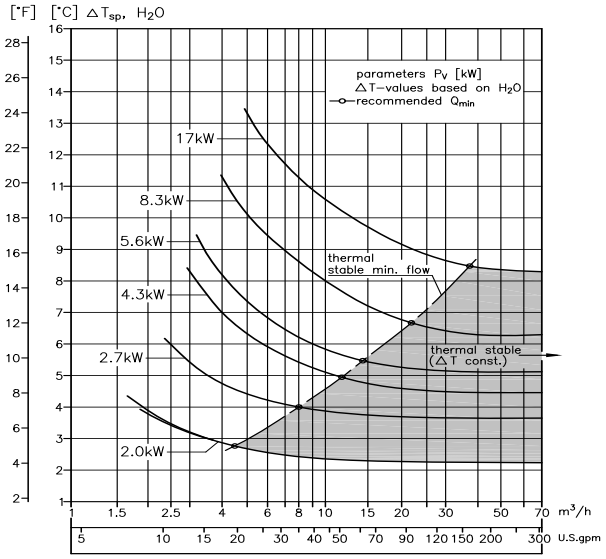
Shell Temperature was increased up to max. 167℃ so that the molten sulfur solidified inside of pump magnetic shell. Finally the motor was tripped by overload motor current.





C. Troubleshooting

Problem	Root Causes	Aspect
① Shell Temperature Increased more than expected	ⓐ Excessive magnetic loss	Design
	ⓑ Insufficient cooling effect by internal cooling flow	Design
※ No Slip of Magnetic Coupling	Magnetic coupling rated torque was higher than motor trip torque	Design



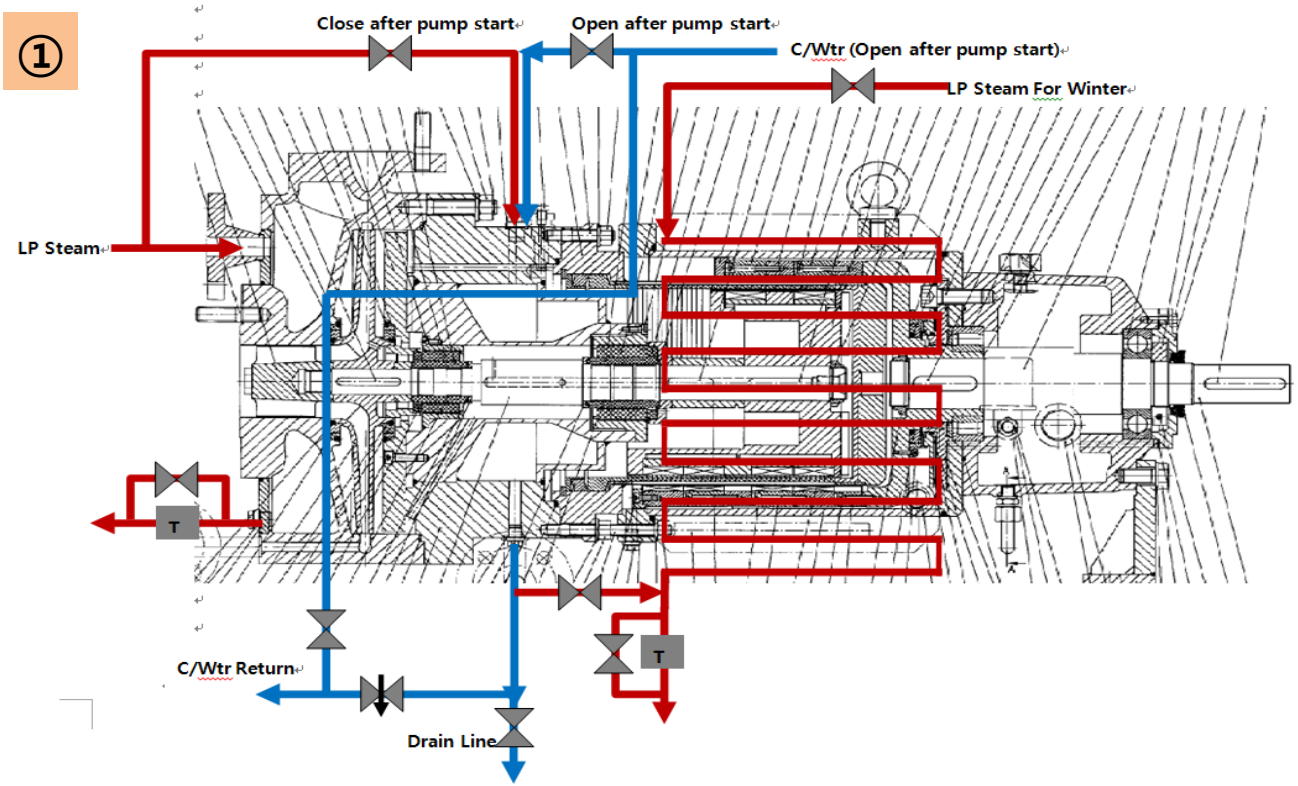
- Expected Temperature Rise : **156.2 ℃**

$$T = T_E + \Delta T_{Sp,H2O} \times \frac{C_{H2O}}{C_{Product}} \times \frac{\rho_{H2O}}{\rho_{Product}}$$

- Actual Temperature Rise : **167 ℃**

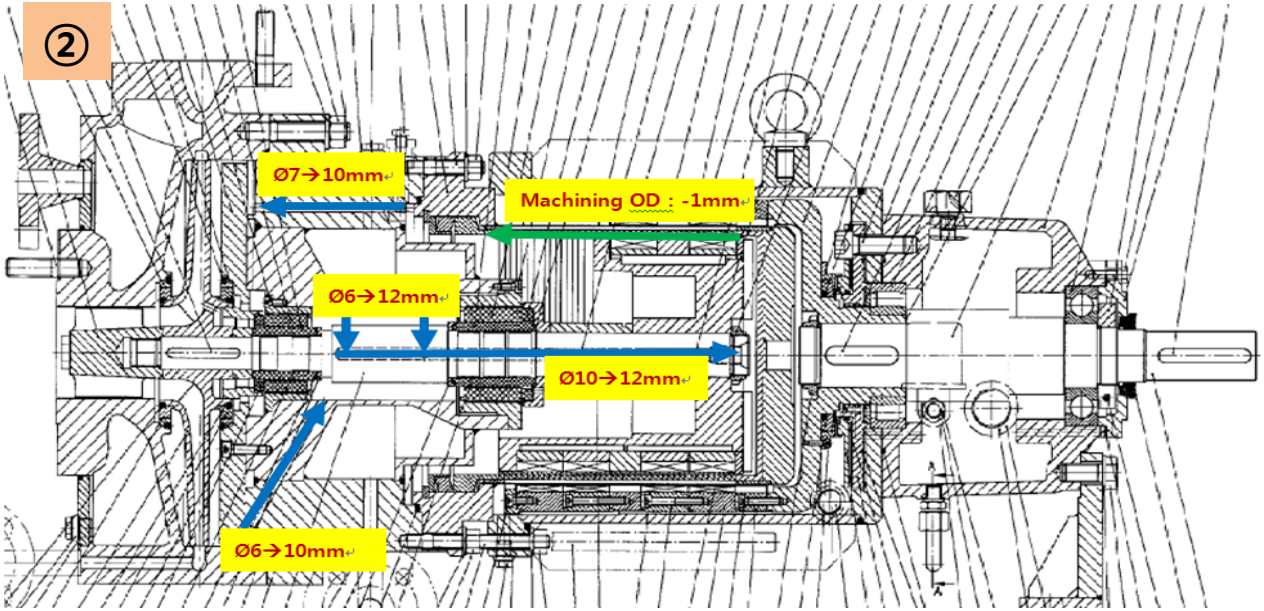
C. Solution Provided and its Result

Root Causes	Solutions Provided	Aspect
ⓐ Excessive magnetic loss	① Modification of Heating & Cooling System - Heating before pump start, - Cooling after pump start	Design



C. Solution Provided and its Result

Root Causes	Solutions Provided	Aspect
ⓑ Insufficient cooling effect by internal cooling flow	② Increase the internal cooling flow	Design

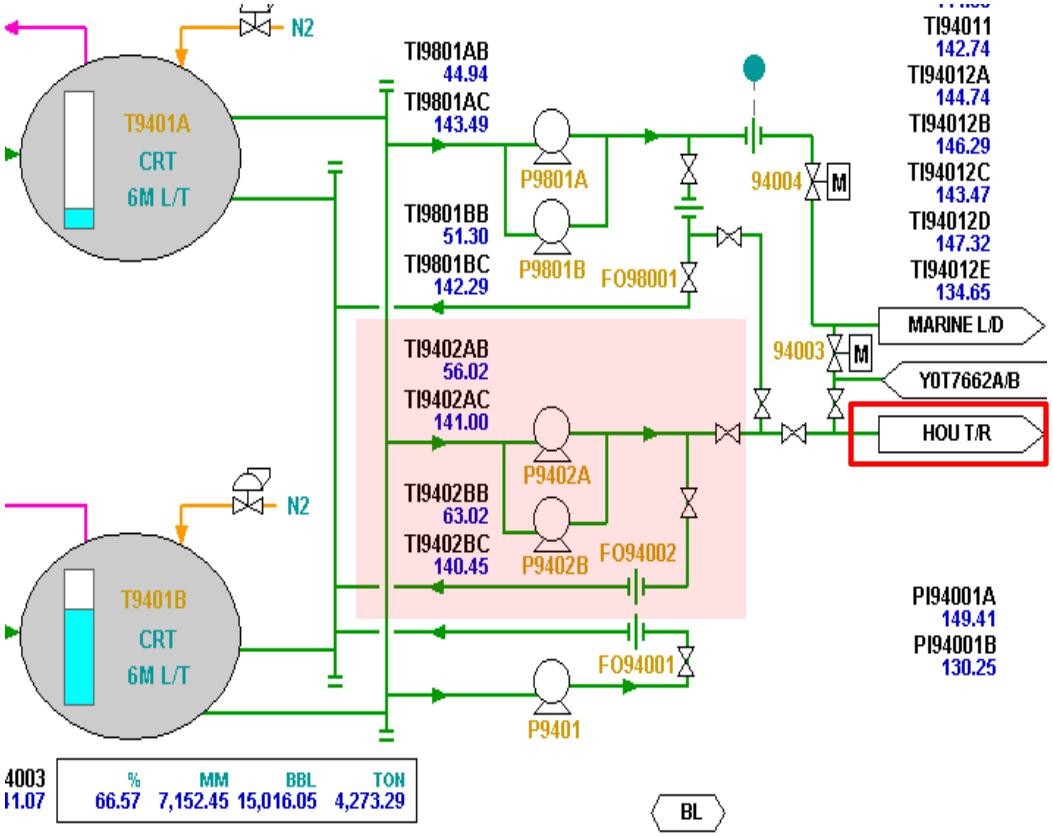


These pumps have been operated stably since 2008 without any trouble (Shell Temperature : 167 → 154 ℃)

3) Sulfur Truck Loading Pump (Y-P9402B)

A. System & Specification of Pump

- This pumps send the molten sulfur from tanks to loading arm for truck loading.

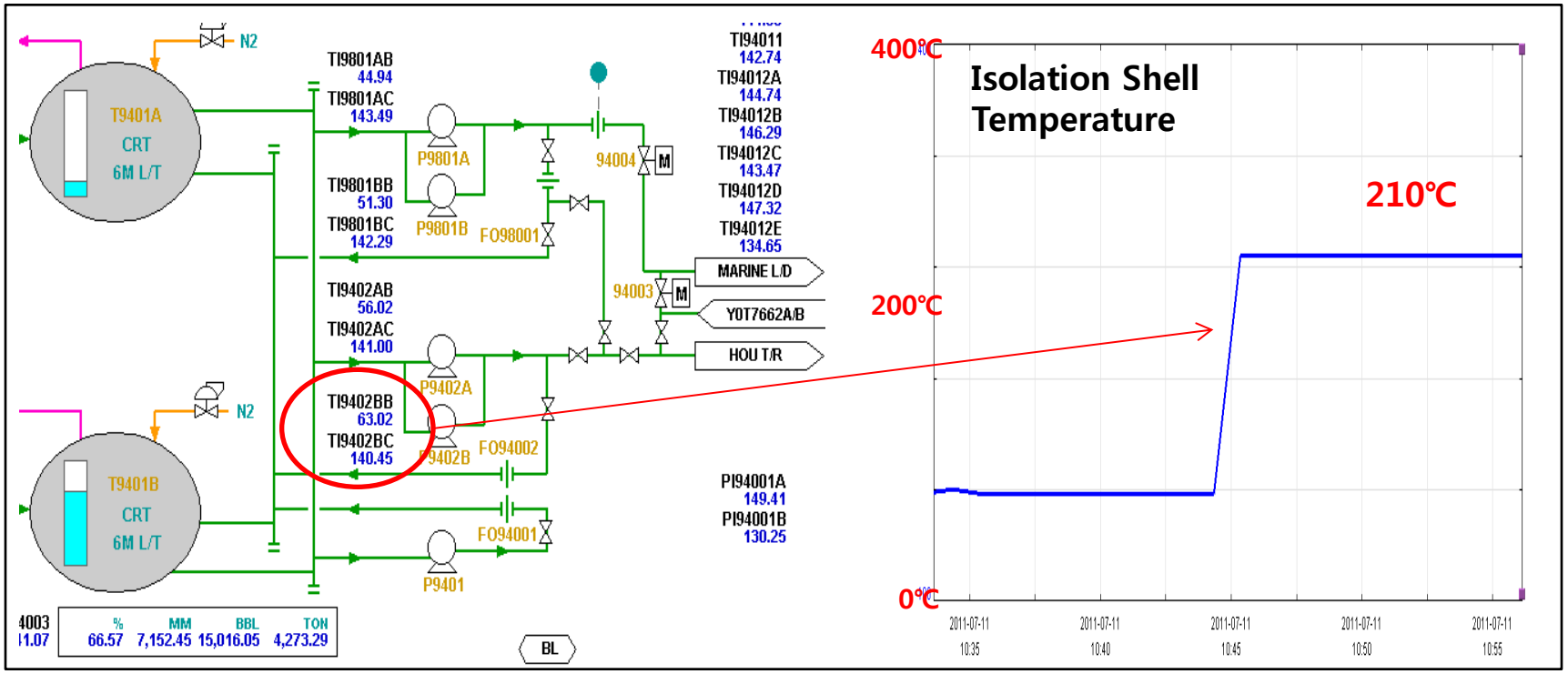


Descript.	Spec.
Service	Molten Sulfur
Temp.	140 ℃
S.G	1.79
Head	101.2 m
Flow	21.5 m3/hr
BHP	36.2 kW
Motor	55kW
RPM	1800

3) Sulfur Truck Loading Pump(Y-P9402B)

B. Problem

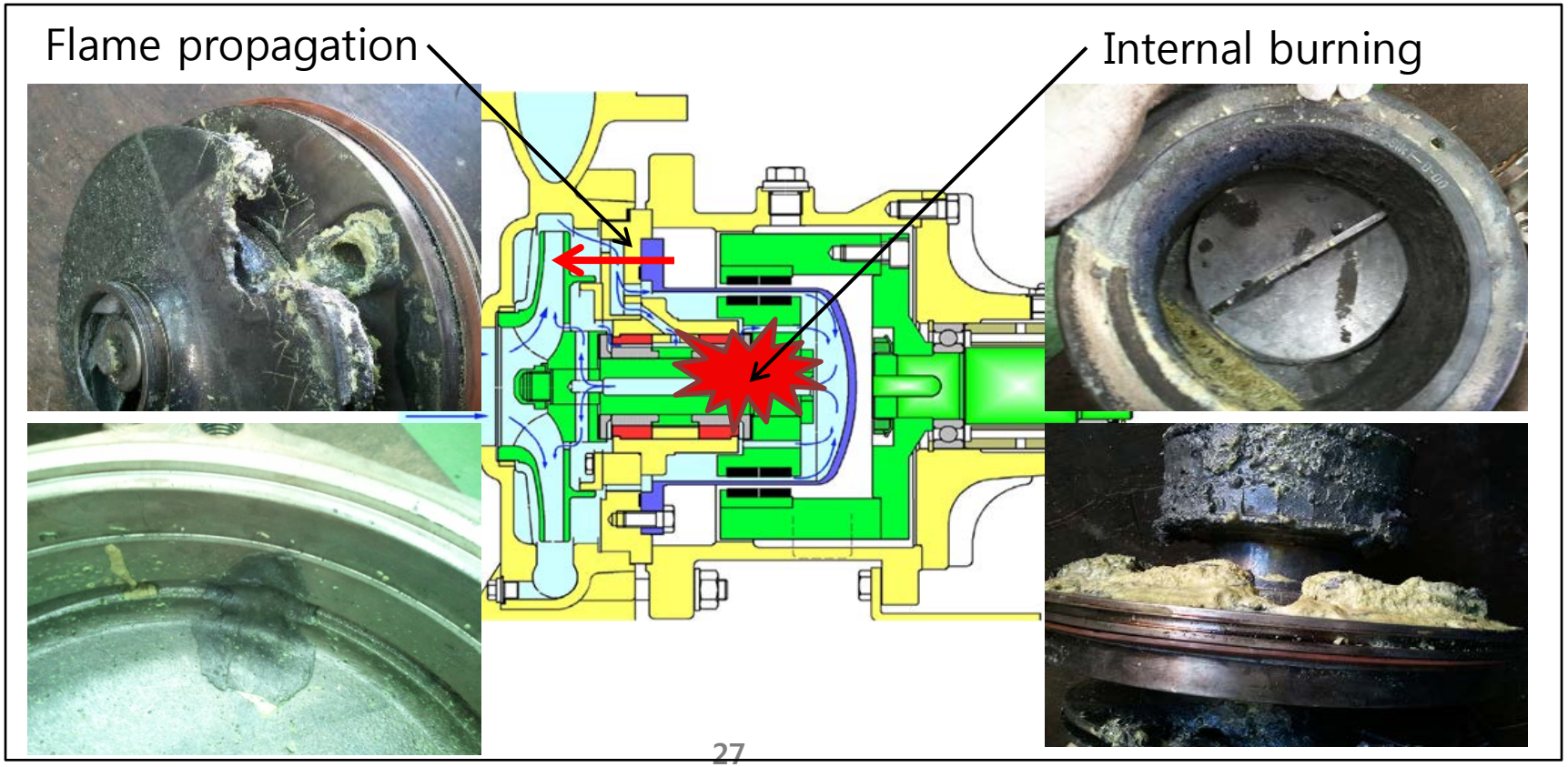
- Pump started and operated for 3 minutes, then smoke was seen coming from the pump.
- Isolation shell temperature increased over maximum temperature sensor range(**210**℃)



3) Sulfur Truck Loading Pump(Y-P9402B)

B. Problem

- Results of overhaul inspection
  - Isolation shell, impeller, casing were partially melted.
  - Inner & outer magnet were demagnetized



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C. Troubleshooting

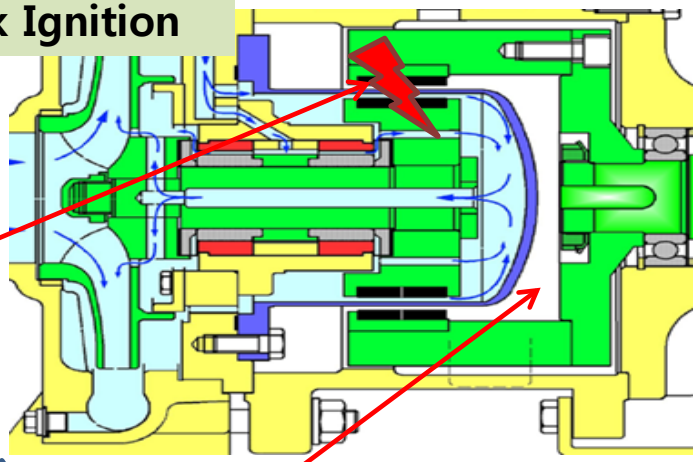
Problem Sequence	Root Causes	Aspect
① Operation under Minimum flow	ⓐ Insufficient a orifice for minimum flow bypass	Design
② Consequential Influence → Excessive heat generation due to operation under minimum flow → Increase viscosity due to excessive heat above 160 ℃ → Torque was increased higher than magnetic rated torque		
③ Magnetic Coupling Slip	ⓑ Magnetic coupling torque was less than motor trip torque	Design
④ Consequential Influence (on next page in detail) → Shell temp. increased due to magnet slip and parts were thermally expanded and finally touched each others → Air entered through damaged shell by contacting with rotating outer magnet → Parts were melted due to high heat generation by reaction of molten sulfur and oxygen. (molten sulfur ignition point : 247℃)		
⑤ Internal parts were damaged and melted	ⓒ Pump didn't stop as soon as magnetic coupling slipped	Protection System

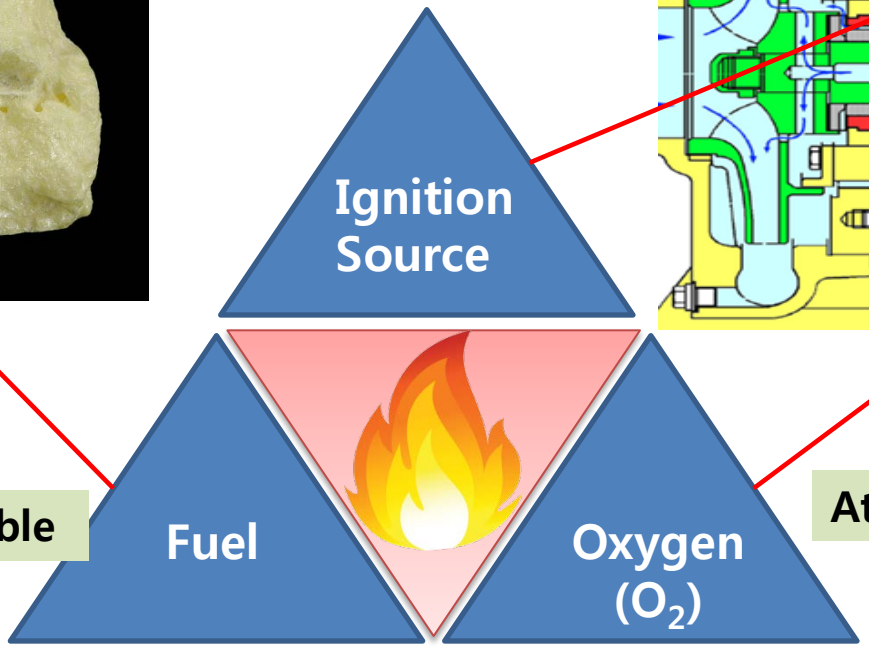
C. Troubleshooting

※ Possible Combustion Mechanism 1

3 elements of combustion : Ignited by Spark due to Parts Metal Contact

Parts Contact → Spark Ignition





Sulfur → Flammable

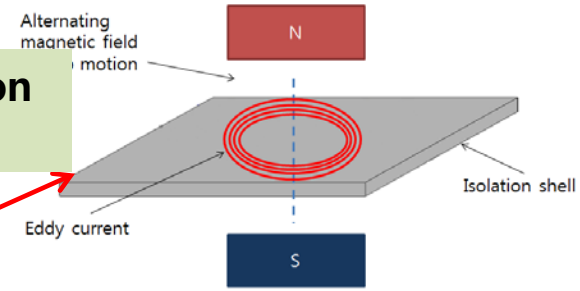
Atmospheric Condition

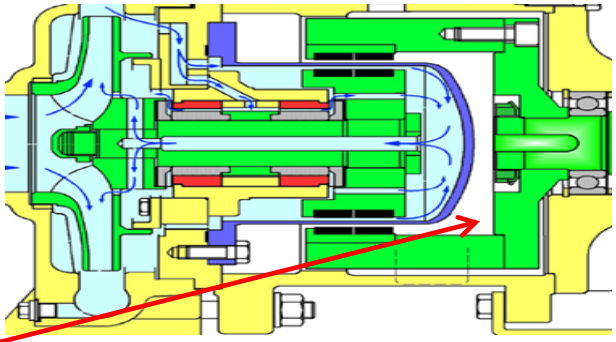
C. Troubleshooting

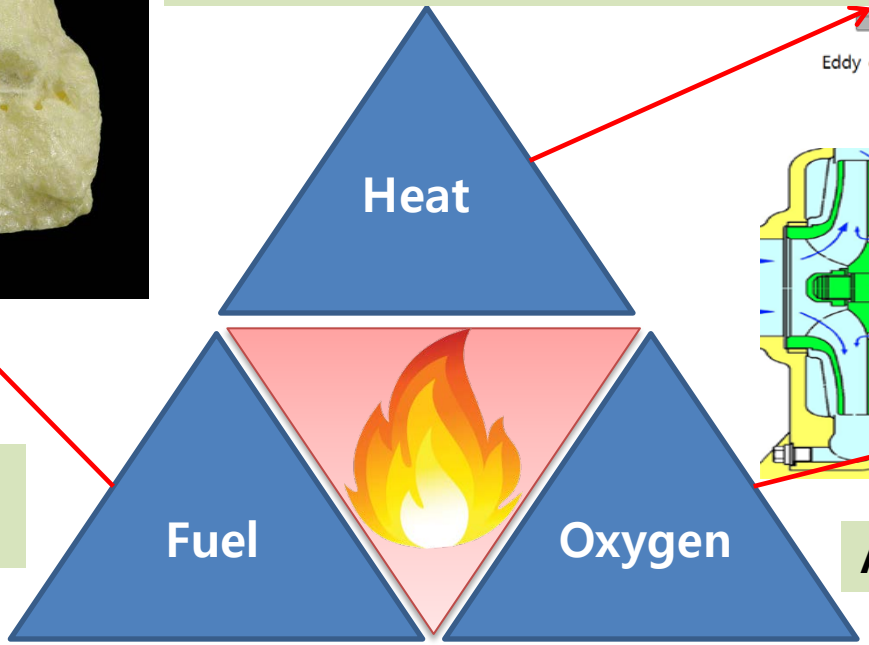
※ Possible Combustion Mechanism 2

Spontaneous Ignited by Heat Generation due to Magnetic Slip

Magnet Slip & Heat Generation
→ Heat Ignition Point : 247℃







Sulfur → Flammable

Atmospheric Condition

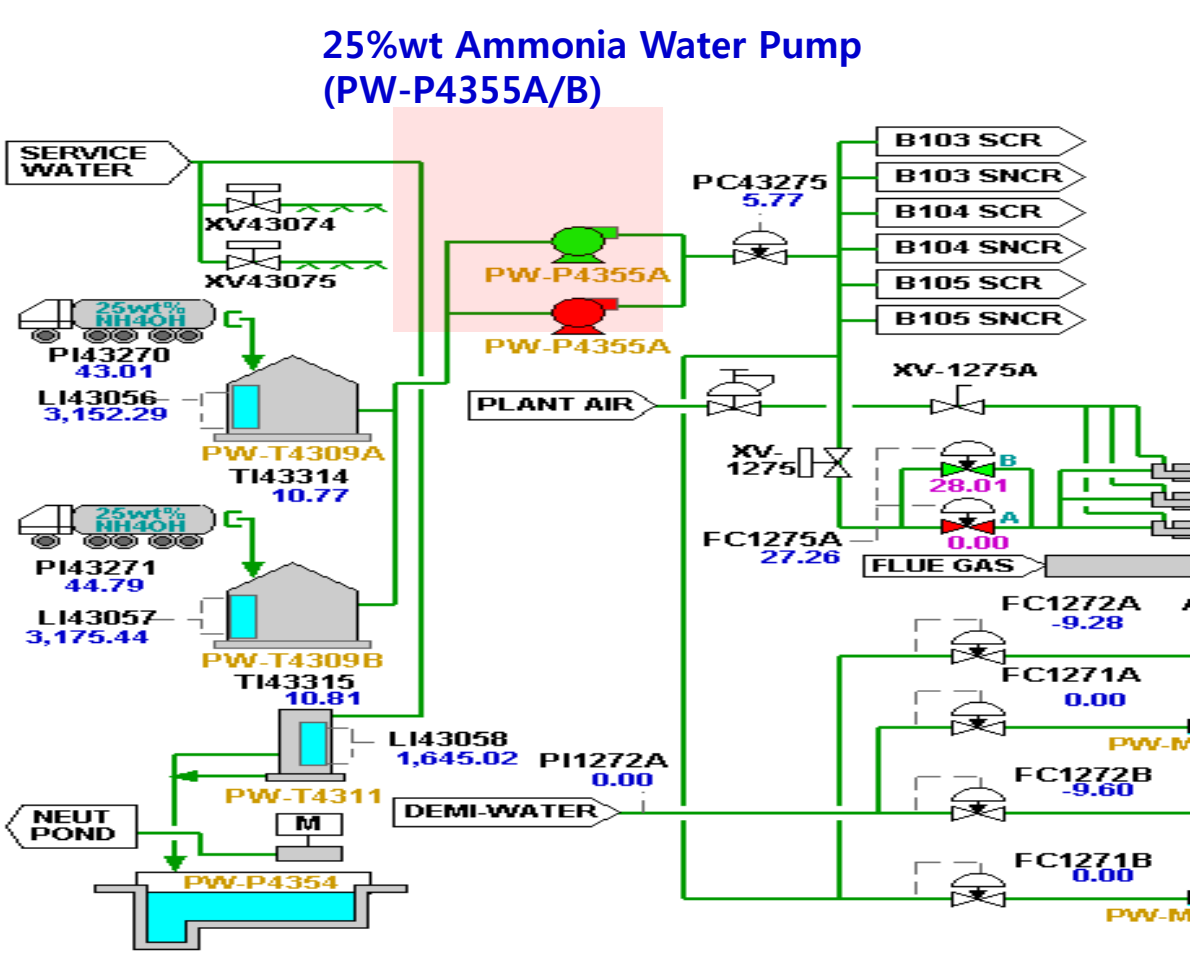
D. Solutions Provided and its Result

Root Causes	Solutions Provided	Aspect
ⓐ Insufficient a orifice Size for minimum flow bypass	▪ Enlarge a orifice size to increase a minimum flow bypass	Design
ⓑ Insufficient Magnetic coupling torque	▪ Increase torque rating of magnetic coupling	Design
ⓒ Pump didn't stop as soon as magnetic coupling was slipped	▪ Implement proper protection system - Shell Temperature Monitoring & High Trip - Motor Amp. Low Trip for slip of Magnetic Coupling	Protection System

These pumps have been operated stably since 2011 without any trouble

A. System & Specification of Pump

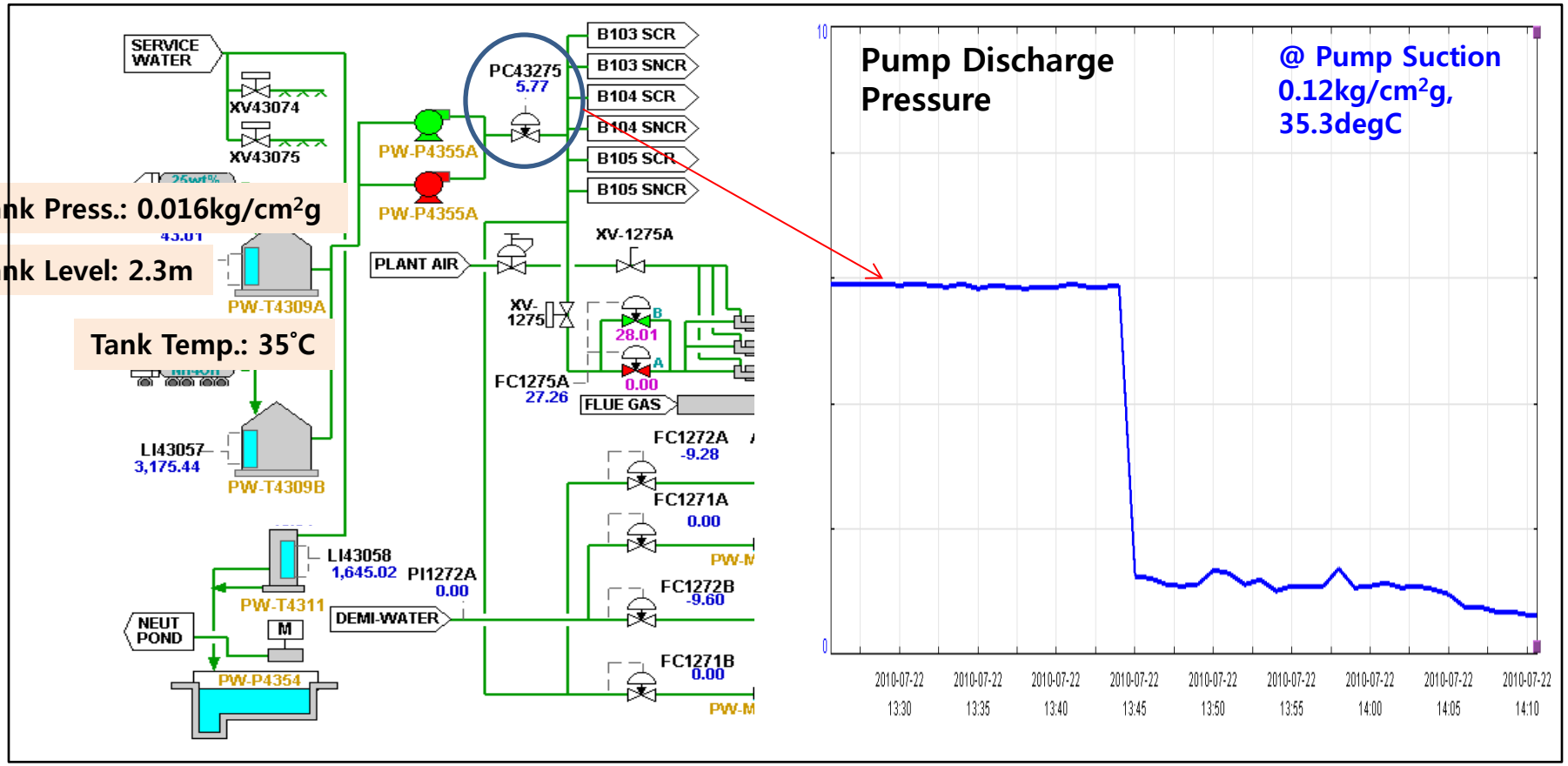
Thease pumps supply a 25% ammonia water to SOx Removal System for boiler.



Descript.	Spec.
Service	Molten Sulfur
Temp.	31.8 ℃
S.G	0.89
Head	66 m
Flow	1.0+0.5 m3/hr
NPSHa	1.37
NPSH3	0.5
BHP	2.99 kW
Motor	5.5 kW
RPM	1800

B. Problem

Discharge pressure of ammonia water pump in SOx Removal System for boiler was decreased (5.9→1.2kg/cm^{2}g), even though stand-by pump was automatically started, the pressure wasn't restored.



C. Troubleshooting

① Suction temperature was +2.2℃ higher than design (Design: 31.8℃, Actual: 34℃)
: Did not properly reflect summer conditions **(NPSHa ↓)**
- Design NPSHav = Ha + Hs – H_f – Hvp(0.872kg/cm2abs) = 1.79 m (@ 31.8℃)
- Actual NPSHav = Ha + Hs – H_f – Hvp(0.950kg/cm2abs) = **0.91 m** (@ 34℃)

② The Heat was generated +3℃ during pumping by Pumping Heat and Magnetic & Bearing Cooling Heat **(NPSH3 ↑)**

- Design NPSH3 : 0.5 m , - Actual NPSH3 : 1.8m

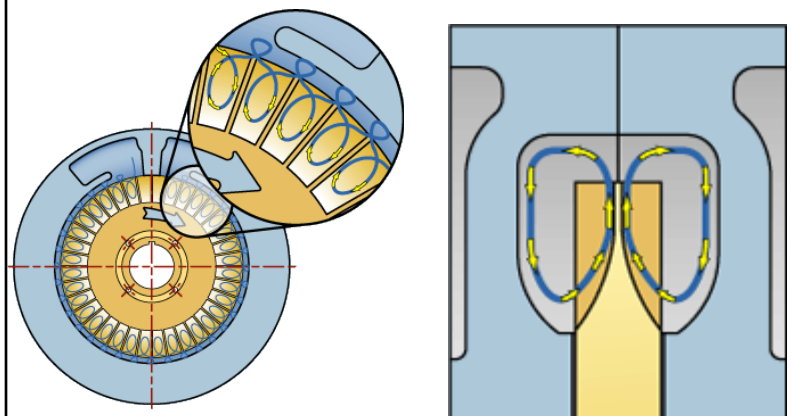
※ **The vapor pressure of ammonia is dramatically changed** according to temperature change

℃	31	32	33	34	35	36	37	38	39	40	41	42	43
Vapor Pressure (kg/cm2)	0.84	0.88	0.92	0.95	0.99	1.03	1.07	1.11	1.15	1.20	1.24	1.29	1.34
Per 1℃ Vapor Pressure Increment (kg/cm2g)	0.034	0.034	0.037	0.038	0.038	0.038	0.038	0.040	0.046	0.046	0.046	0.046	0.046
Per 1℃ NPSHa decrement (m) (or NPSHr increment)	0.38	0.38	0.42	0.43	0.43	0.43	0.43	0.45	0.52	0.52	0.52	0.52	0.52

C. Troubleshooting

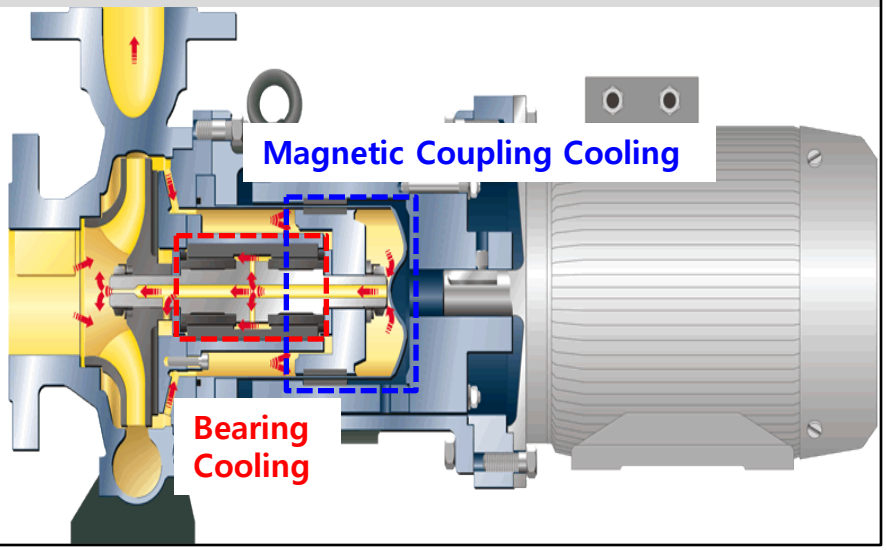
Problem	Root Causes	Aspect
① **Pressure Drop due to Cavitation**	ⓐ **Decreased NPSHa** Suction temperature was +2.2℃ higher than design	**Operation**
	ⓑ **Increased NSPSH3** Heat generation (+3℃) during pumping by Pumping Heat and Magnetic & Bearing Cooling Heat	**Design**

Pumping Heat Generation



Regenerative Turbine Type Pump

Heat Generation by Internal Cooling



D. Solution Provided and its Result

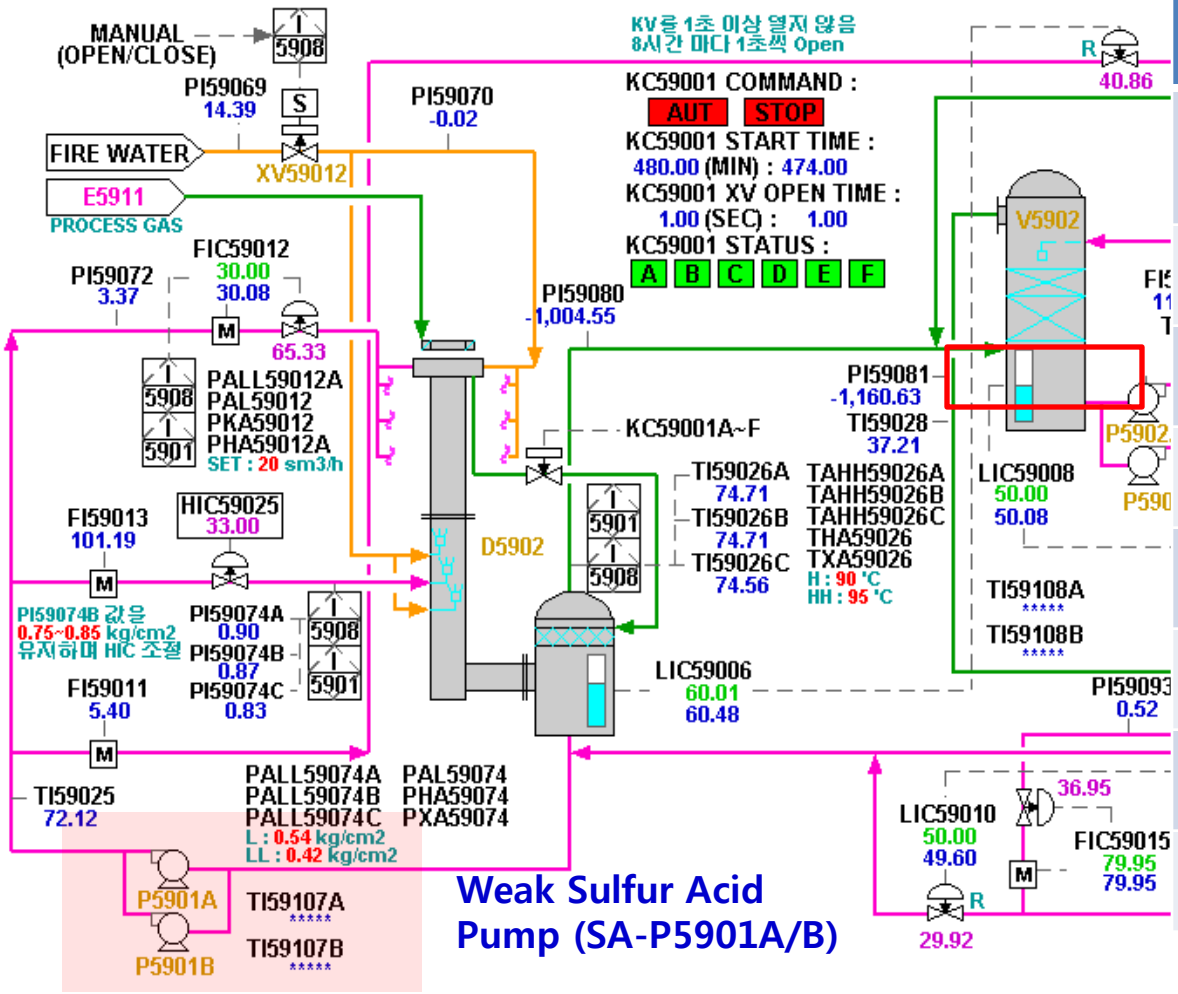
Root Causes	Solution Provided	Aspect
ⓐ Decrease NSPSHa	▪ **Improvement of NPSHa** - **Protect pump suction line from radiation of sun** - **Increase Tank Level for summer**	**Operation**
ⓑ Increase NSPSH3	▪ **Water jacketing for casing cooling**	**Design**
ⓒ Additional Remedy	▪ **Implement proper protection system** - Shell Temperature Monitoring & High Trip - Motor Amp. Low Trip for slip of Magnetic Coupling	**Protection System**

These pumps have been operated stably since 2010 without any trouble

A. System & Specification of Pump

Failure Case

This pumps circulate a weak sulfuric acid including dirty particles on reverse jet quencher in SAR plant.



Weak Sulfur Acid Pump (SA-P5901A/B)

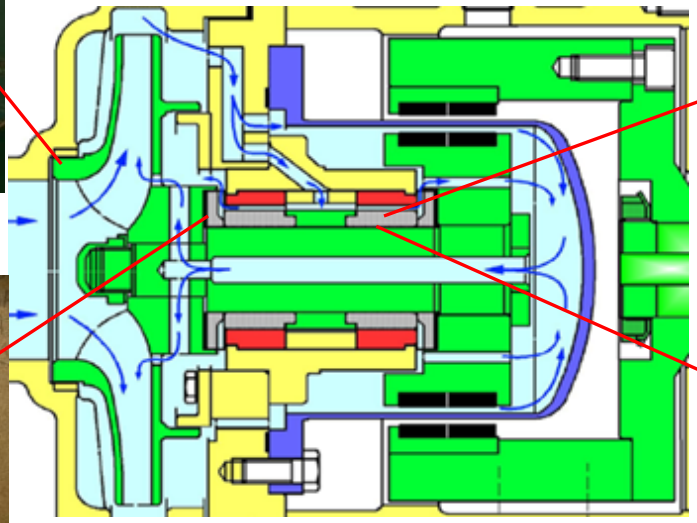
Descript.	Spec.
Service	**Weak(2.56%)** Sulfur Acid
Temp.	85 ℃
S.G	1.05
Head	35.5 m
Flow	156 m3/hr
BHP	27.8 kW
Motor	37kW
RPM	3600

B. Problem

Internal parts were damaged **more than 30 times** during 2008~2012.

Impeller Damage

Thrust Bearing Damage



Sic Sleeve Bearing Damage

Tolerance Ring Damage

C. Troubleshooting

Problem	Root Causes	Aspect
① **Internal part corrosion**	ⓐ **Improper material** CD-4MCU couldn't resist for weak acid service	Design
② **Flow reduction**	ⓑ **Internal damage by process foreign material** Internal parts were damaged by process foreign material	Design
	ⓒ **Poor external flushing** External flushing source is not 100% pure	Operation
	ⓓ **Tolerance ring** Bearing holding force of tolerance ring decreased as time goes by because of loosing elasticity of it	Design

D. Solution Provided and its Result

Root Causes	Solution Provided	Aspect
ⓐ Improper material	▪ Improvement of material - CD-4MCU → Hastelloy-C	Design
ⓑ Process foreign material	▪ Dual strainer	Design
ⓒ Poor external flushing	▪ Change to pure external source (Demi-water)	Operation
ⓓ Tolerance	▪ Change bearing type (no tolerance ring)	Design

Despite of many improvement application, the pump reliability couldn't be improved. Finally the pump type was changed to conventional seal pump

3. Lessons Learned

In case of magnetic pump application for special services such as molten sulfur and ammonia, the following should be taken into consideration.

Engineering & Design	▪ Specify the **limit of temperature rise** and include the temperature rise test in performance test at engineering stage ▪ Install the **protection and monitoring system** for the shell temperature and ampere for coupling slip ▪ The **torque rating of magnetic coupling** should be higher than motor trip torque to avoid the slip of magnetic coupling. ▪ Install **special strainer** on shell flushing line if abrasive foreign material would be expected. ▪ Restrict its application to **a corrosive service including particles**

3. Lessons Learned

In case of magnetic pump application for special services such as molten sulfur and ammonia, the following should be taken into consideration.

Operation	▪ Install and size **enough minimum by-pass flow orifice** ▪ Recommend **no parallel operation** for pumps with flat curve If parallel operation would be required, the head rise should be more than 110%. ▪ Recommend to operating these types of pumps **within design temperature**

End Of Presentation

&

Questions?

References

[1] The Viscosity of Liquid Sulfur, Tomoo Matsushima , The Research Institute of Mineral Dressing and Metallurgy (Received September 16, 1959)
[2] Aqua Ammonia Information Manual, LAROCHE Industries Inc