Unexpected Problems with Kettle Reboiler Circuit

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Outlines

- FRI Experimental Facility & Operations
- Kettle Reboiler Circuit & Its Common Problem
- Unexpected Kettle Problem 1
- Unexpected Kettle Problem 2
- Lessons Learned
- Concluding Remarks

About FRI

- FRI is a research consortium funded and directed by over 85 members worldwide
- Research at FRI is focused on mass transfer and hydraulic behavior of gases and liquids in distillation, absorption, and stripping equipment
- FRI has a history of close to 70 years of research data, correlations, reports, computer program, and handbooks that are all available to members only.

WHO IS FRI?

Established in 1952

Commercial Scale Distillation Research

FRI has the only independent commercial scale distillation equipment operating with hydrocarbon systems at pressures ranging from deep vacuum to 500 psia.

Conducting such research is too expensive for any one company

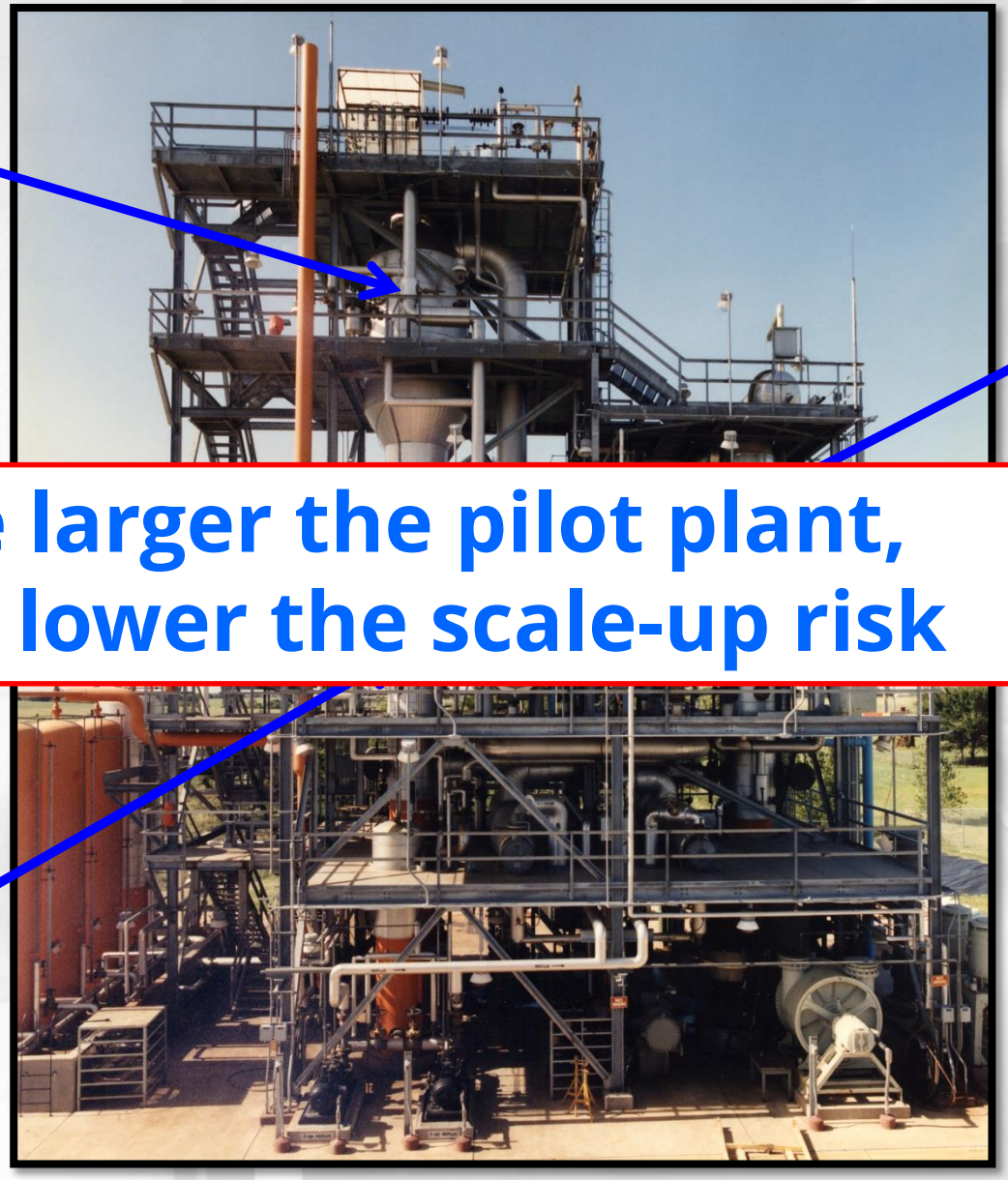
Over **60% of FRI's Membership** is International and Includes the World's Leading Chemical, Engineering, and Petroleum Companies

FRI is Member Driven.

Each Member has a Vote on the Direction of the Research Program.

FRI EXPERIMENTAL FACILITY

Low Pressure Column
2.44m(8ft) Dia.
3.7m(12ft) Height



High Pressure Column
1.22m(4ft) Dia
8.4m(28ft) Heigh

The larger the pilot plant, the lower the scale-up risk

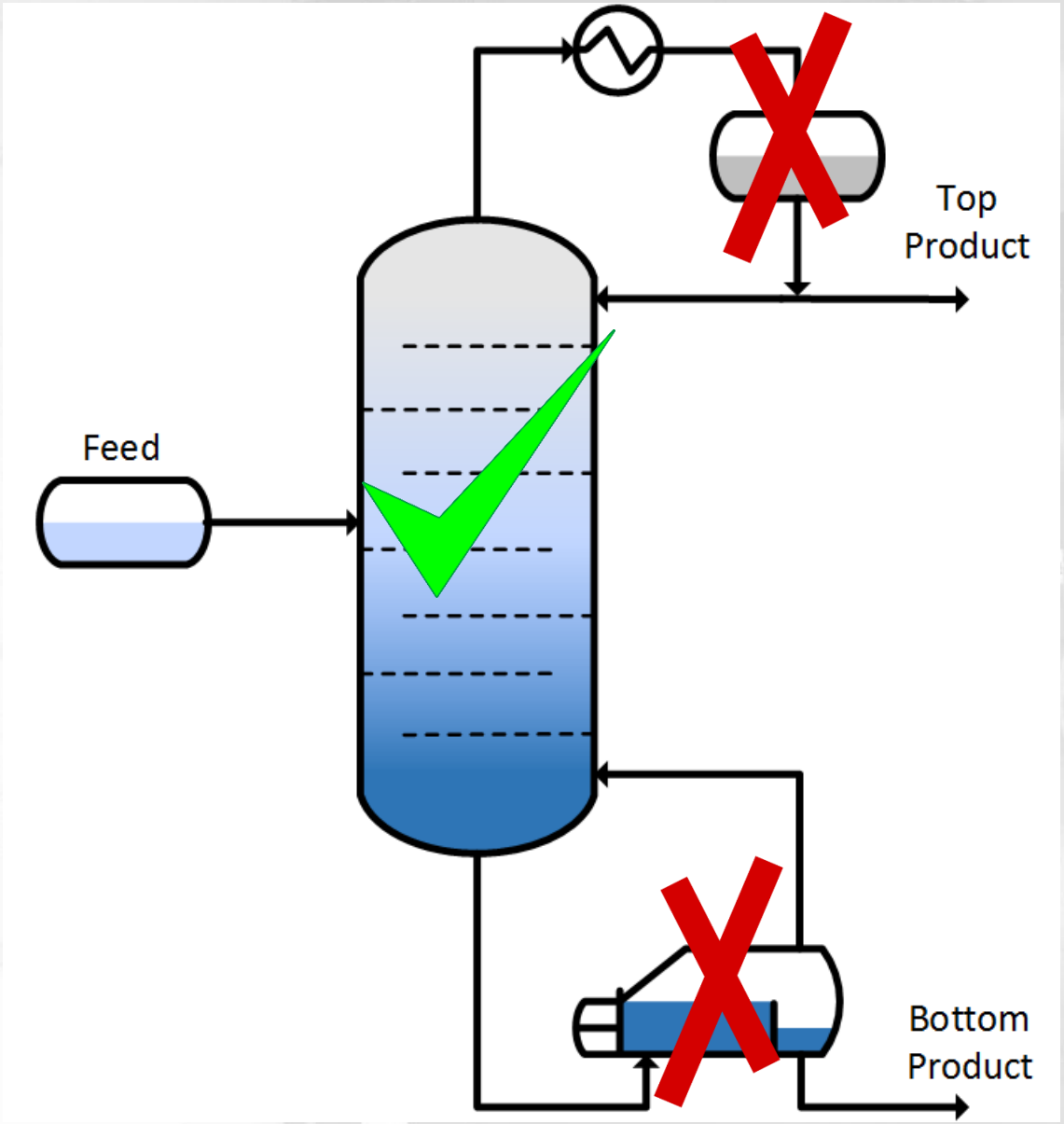
Low Pressure Column
1.22m(4ft) Dia.
8.4m(28ft) Height

FRI EXPERIMENTAL FACILITY

FRI Operations

- Multiple test systems
  - iC4/nC4 (6.9 -35 bara)
  - C6/C7 (0.31 -3.5 bara)
  - p/o xylene (16 -760 mmHga)
- Wide range of physical properties and process conditions
  - 10% - 100% flood capacity
- **Steady state is a luxury at FRI**

Distillation Column Problems

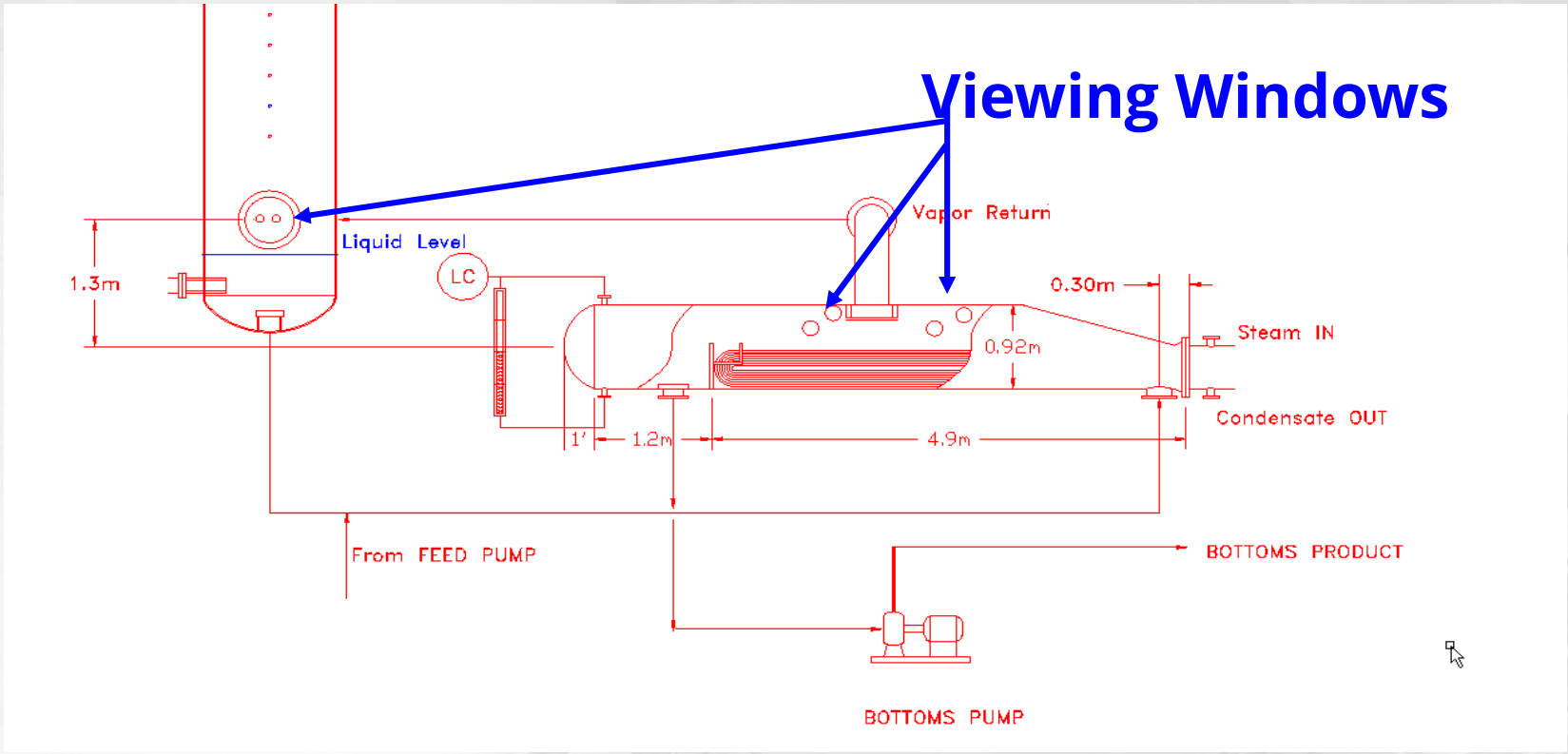


Kettle Entrainment Problems

- Kettle reboilers are most troublesome reboiler type in the chemical process industries (CPI)**
- Kettle operations are often limited by entrainment

** HZ Kister, Chemical Engineering, Feb 2010

FRI Kettle Reboiler Overview



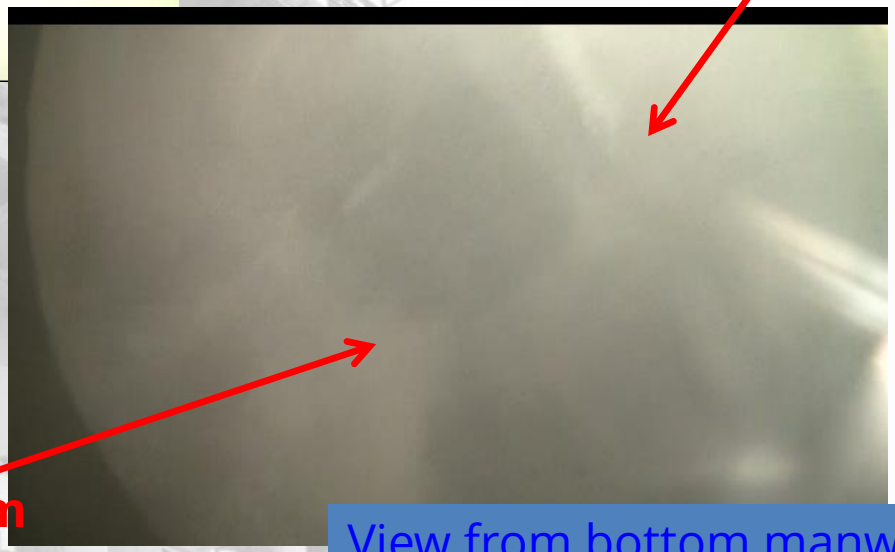
Design Parameters	
Reboiling Rating	15 (4.4) MMBtu/hr (MW)
Steam Supply Temp.	320-350 (160 – 177) °F (C)
Process Side Boiling Temp	140-290 (60 – 143) °F (C)
Mass flow of Steam Condensed	~260 (118) lb/min (kg/min) at 15 MMBtu/hr

Kettle Entrainment Problem

- Entrainment causes:
  - >Higher pressure drops across the vapor return line
  - >>higher liquid level on the bottom of the column
  - >>>if the level is too close to the vapor return nozzle, resulting in unstable operations, liquid entrainment to the packed bed and/or trays-→prematurely flooding

C6/C7 @1.62bara with 36kW/m^2 Heat Flux

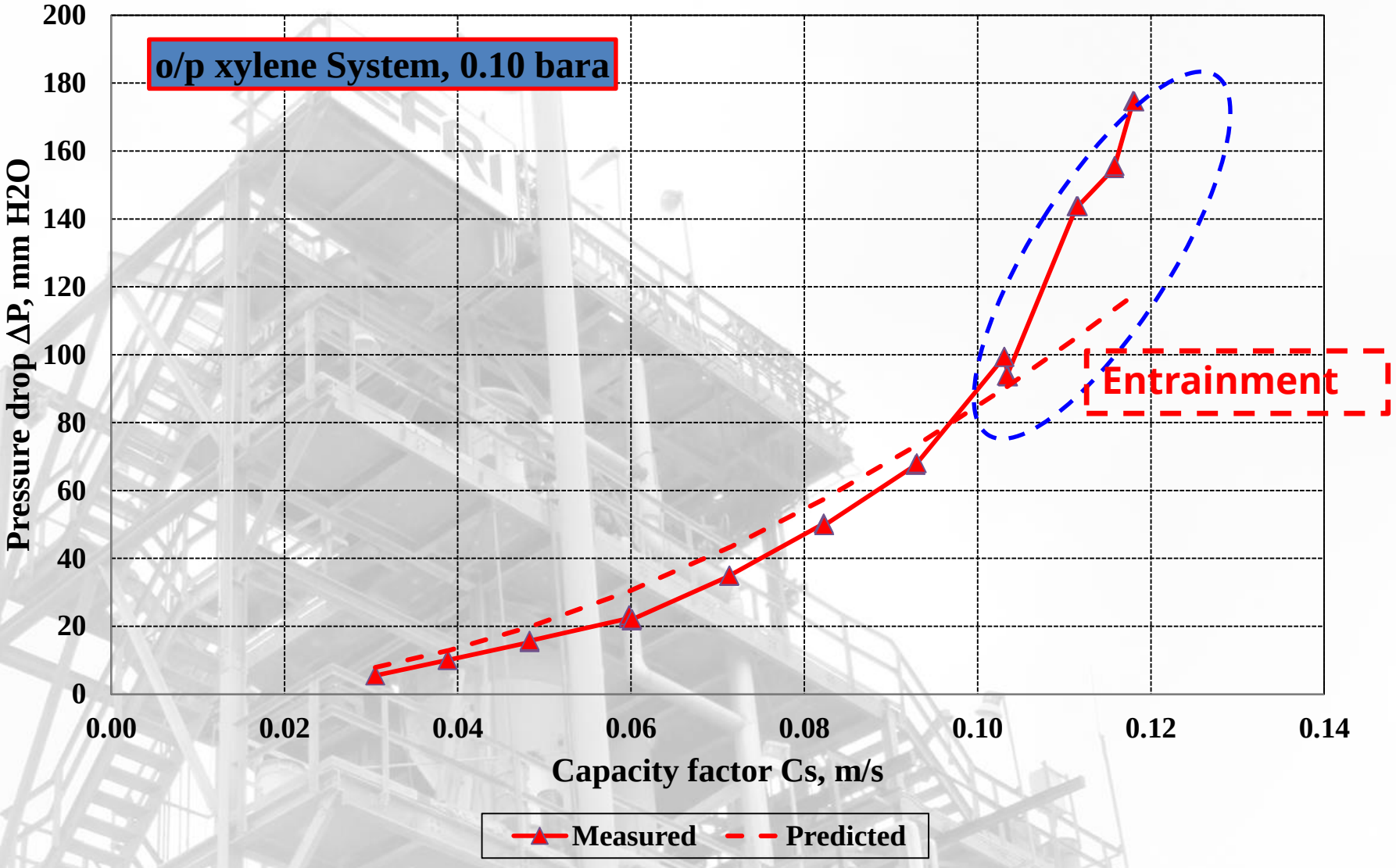
Column Vapor Nozzle



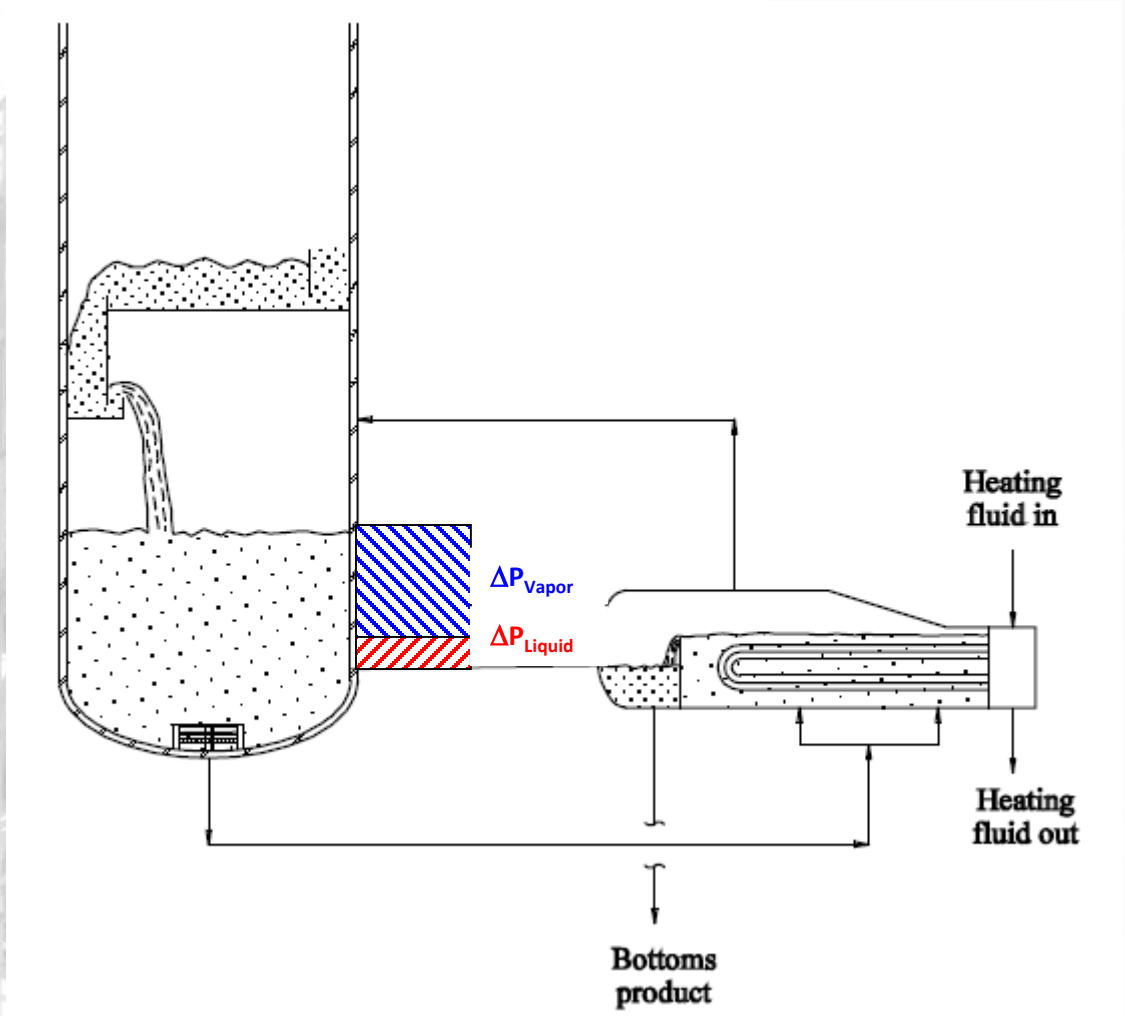
Heavy liquid stream

View from bottom manway across the vapor return nozzle

Pressure Drops across the Vapor Return Line



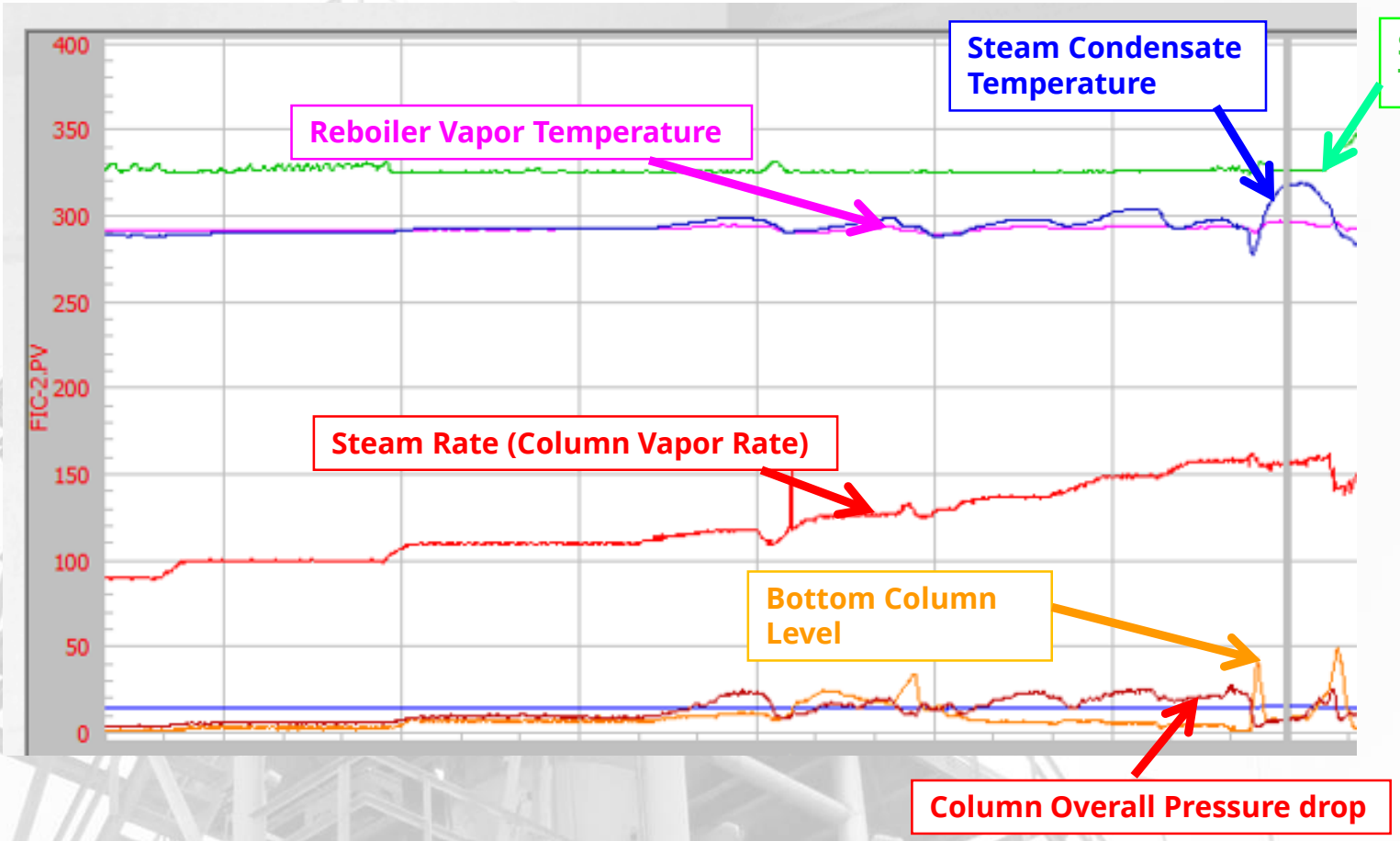
Kettle Reboiler Circuit



Unexpected Problem 1

- Symptom
  - While increasing the reboiler duty, the column behaved like that it was flooded, but at a vapor rate much less than expected
  - The reboiler duty at this operating pressure was much lower than design duty

Operation Trends



Observations

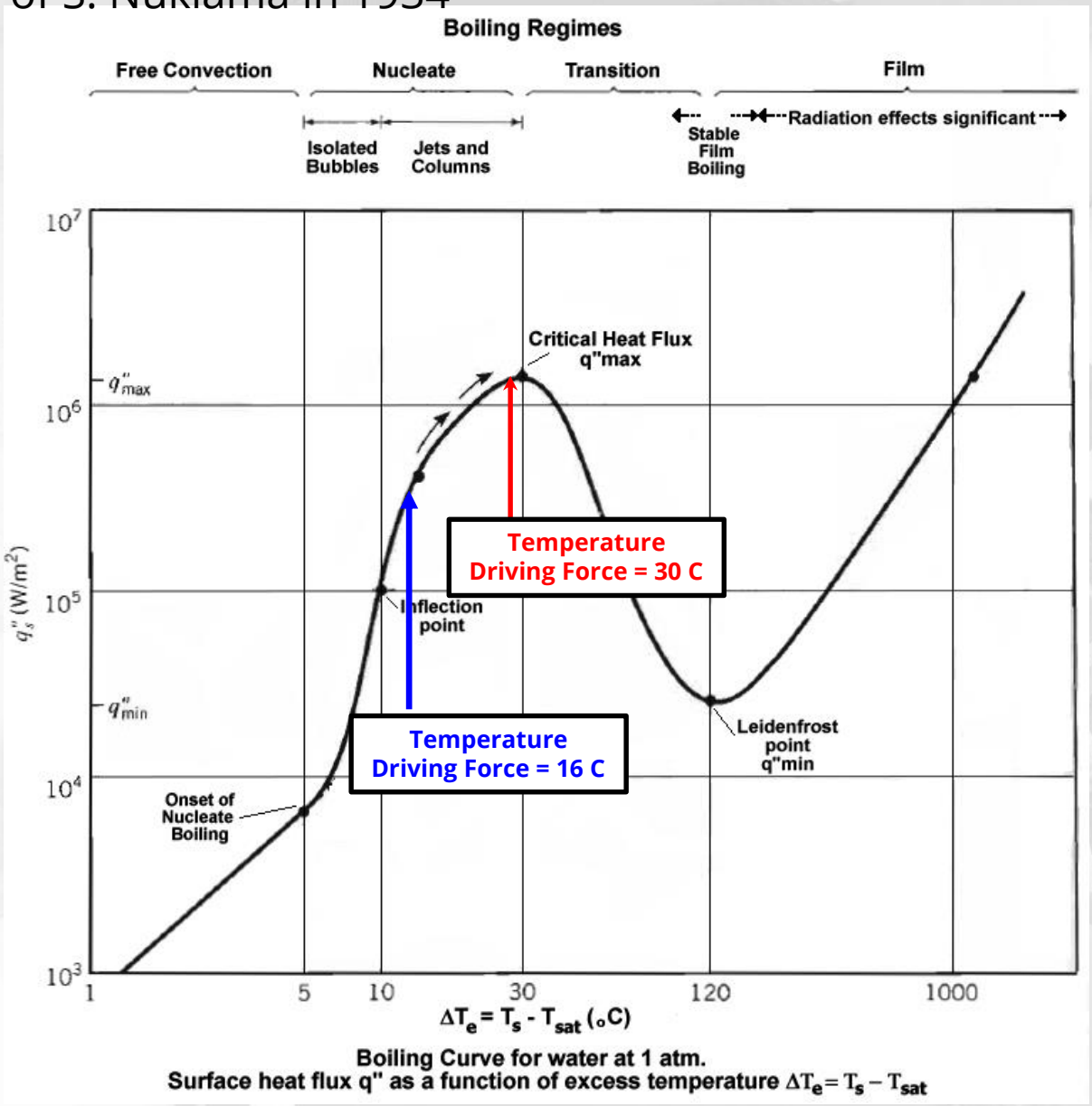
- Level in bottom of column abnormally high
- Bottom half of column higher than top half pressure drop
- Atypical to normal flood behavior; much less flooding vapor rate than expected
- Steam condensate temperature erratic
- Spikes in bottom column level

Investigation & Troubleshooting

- When the column operating pressure was reduced to certain value, all symptoms were gone
- **WHY??**
- **Basic and fundamental**

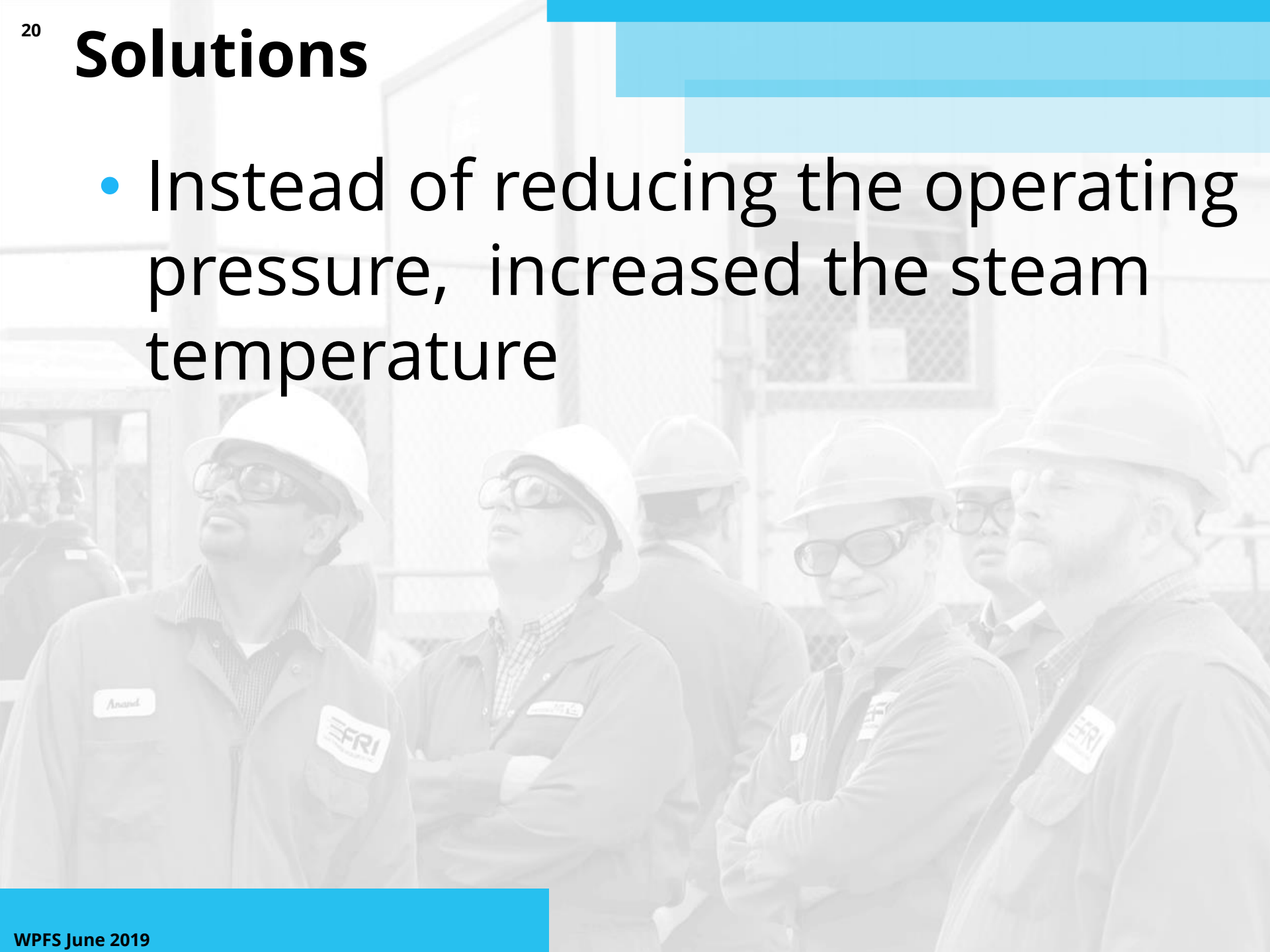
Boiling Regimes

Graph courtesy of S. Nukiama in 1934

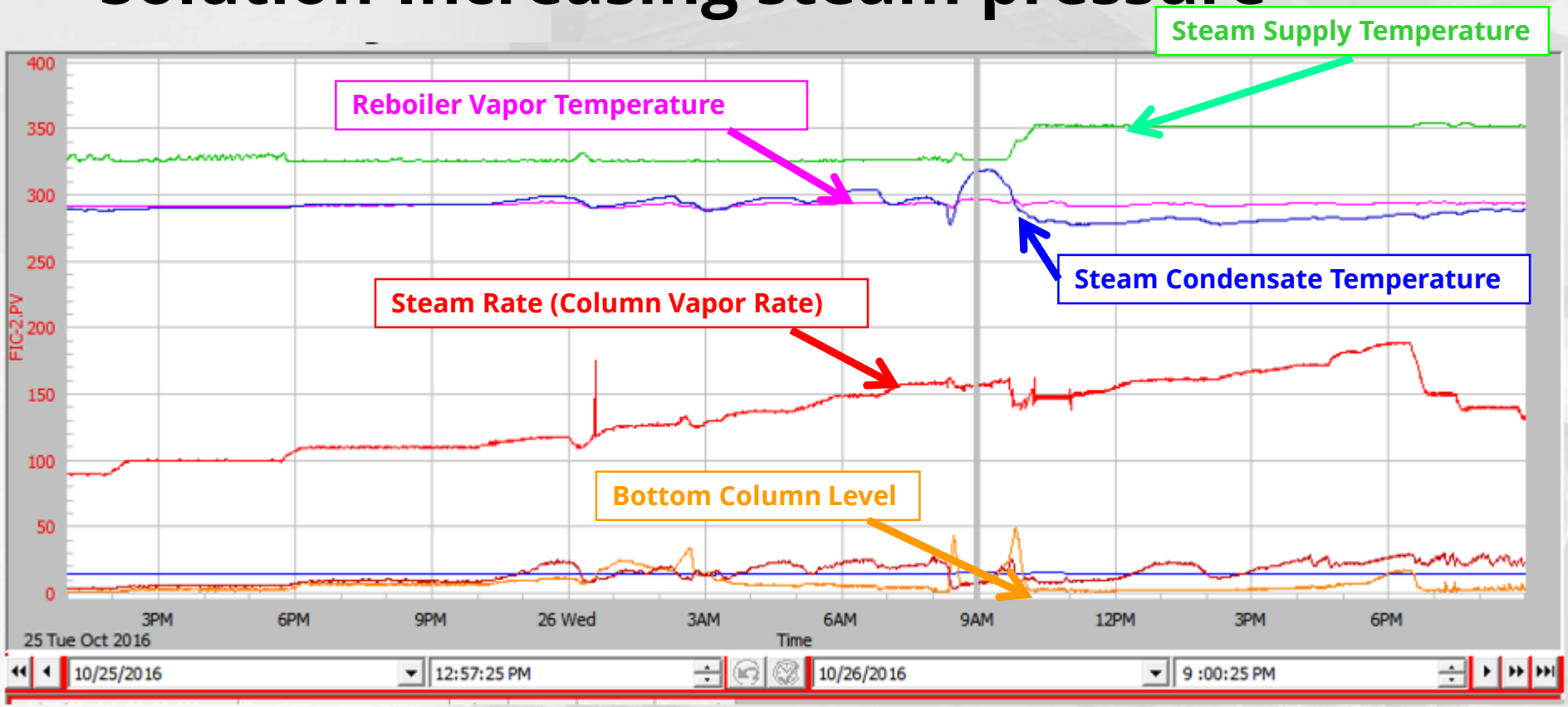


Solutions

- Instead of reducing the operating pressure, increased the steam temperature



Solution-Increasing steam pressure



In this case, capacity increased by ~19% by operating with larger temperature driving force in reboiler

Results

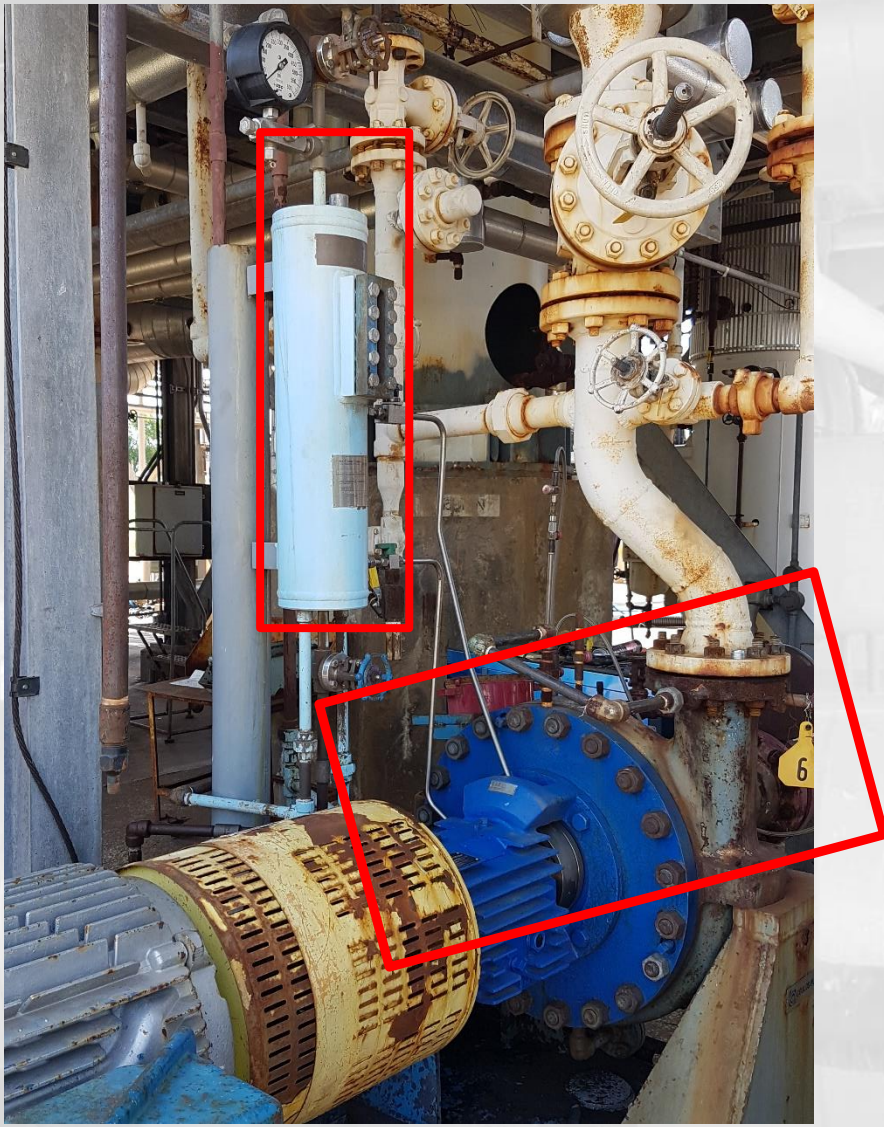
- Steam condensate temperature began decreasing, indicating complete condensation
- Drastic reduction in column pressure drop and bottom column level
- Vapor rate was able to be increased without any operational problems and the testing device was hydraulically flooded

Lesson learned

- Column hydraulic problems are not always caused by high vapor and liquid loadings
- The hydraulic problems might have caused by the heat transfer limitation
- While changing process conditions, it us necessary to pay attention to the driving force for the heat transfer

Unexpected Problem 2

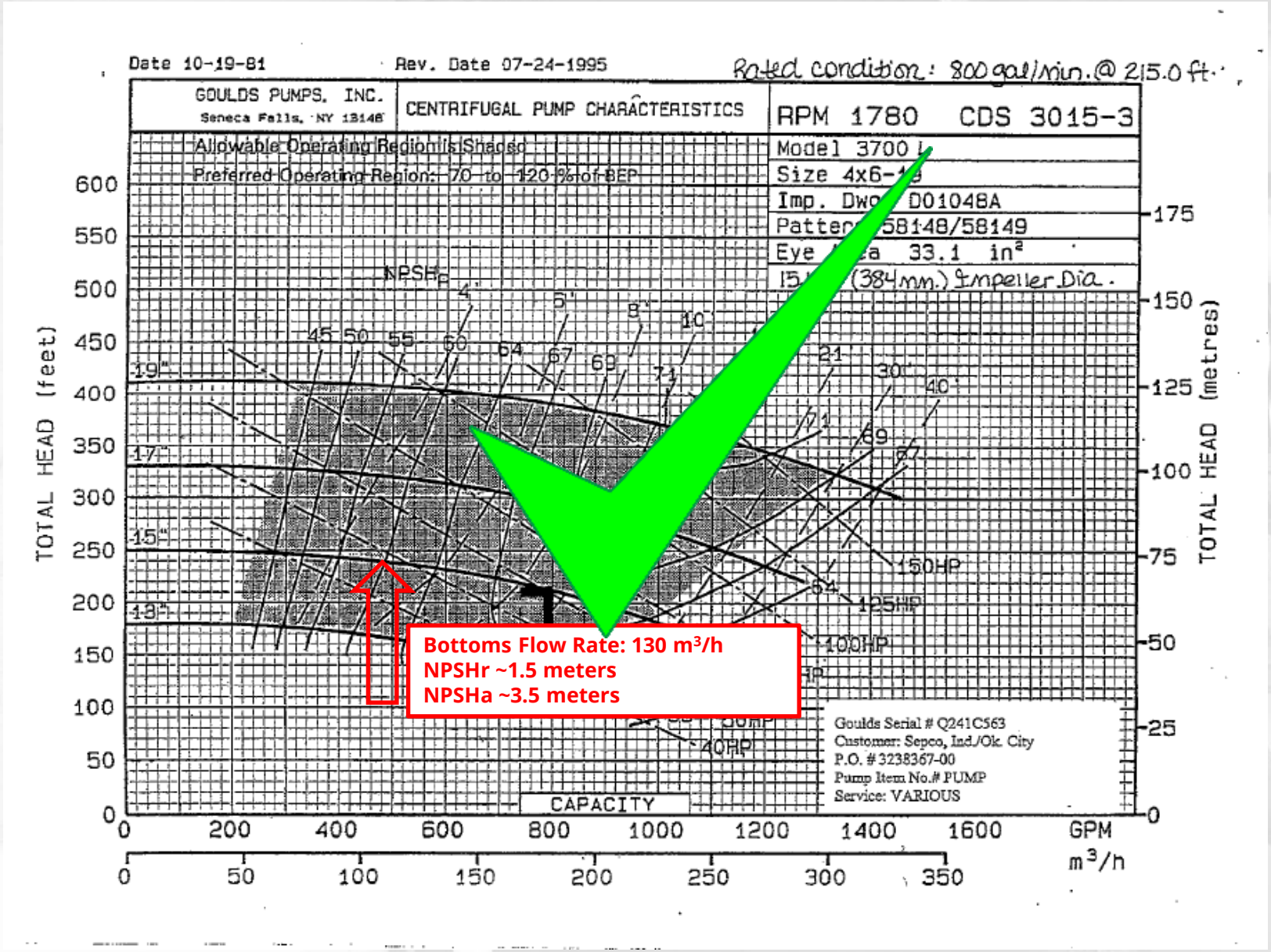
- Problems:
  - Experienced cavitation type of problem with the bottom pump, during iC4/nC4 operations at 27 bara (400psia)
  - Caused pump mechanical seal failure
- Symptoms:
  - Very loud pump noise
  - C4's spilled out of the seal pot vent



Investigations

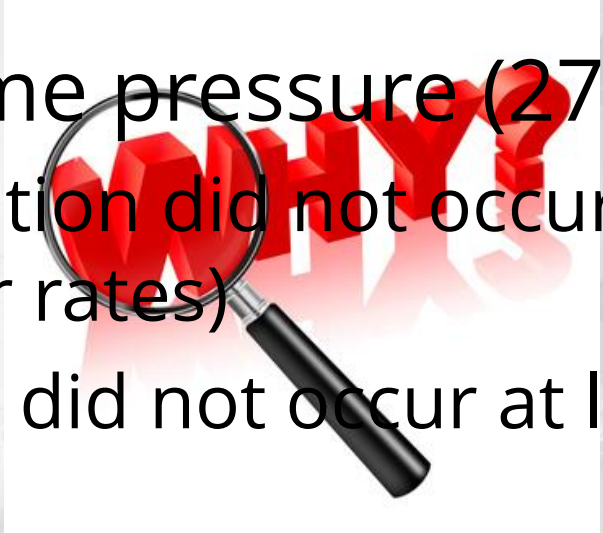
- Cavitation?
  - NPSHr (Net Positive Suction Head required) by the pump
  - The NPSHa should always be one to two feet (0.3 to 0.6 m) above the NPSHr of the pump to prevent cavitation

Pump Curve

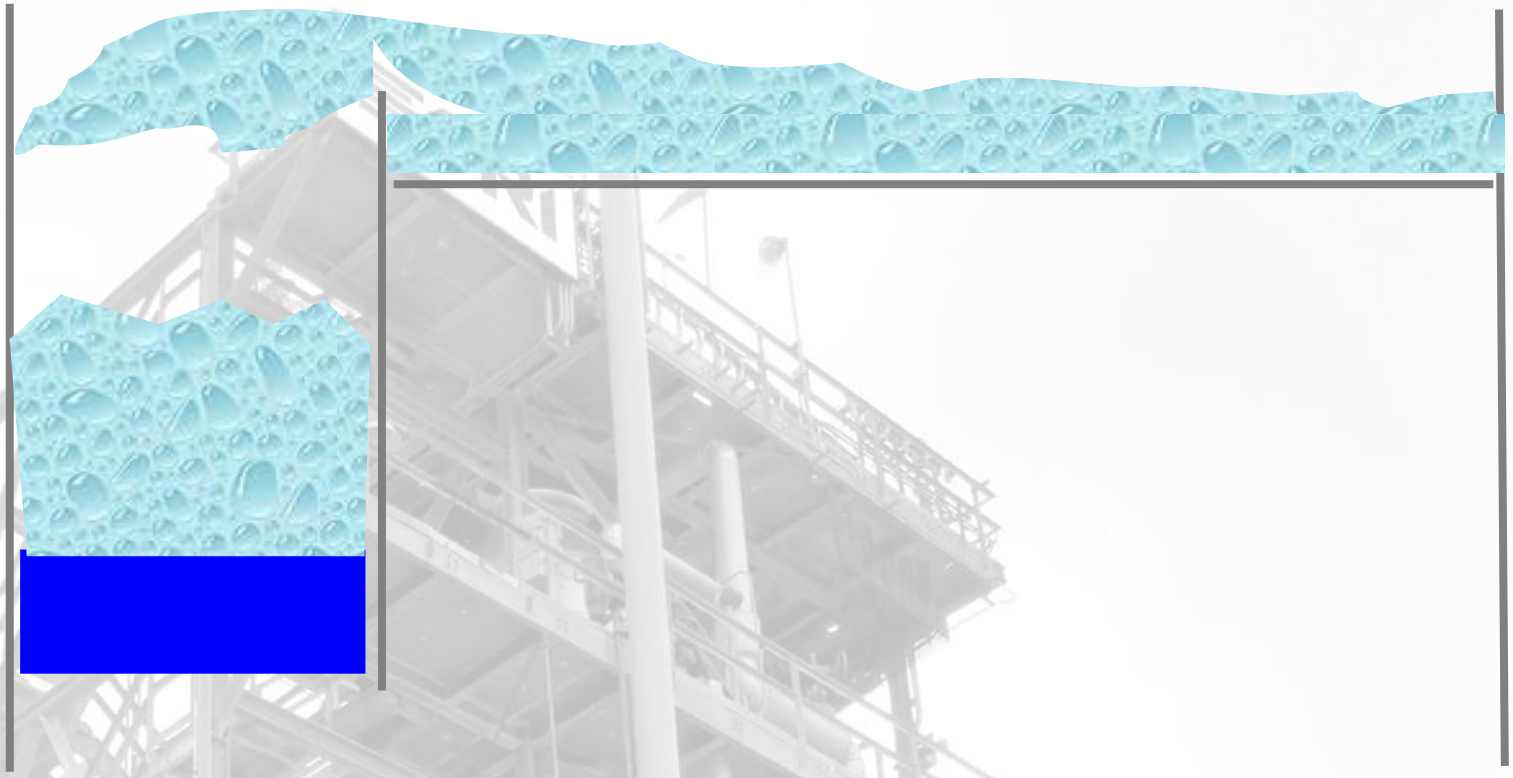

Date 10-19-81
Rev. Date 07-24-1995
Rated condition: 800 gal/min. @ 215.0 ft.
GOULDS PUMPS, INC.
Seneca Falls, NY 13148
CENTRIFUGAL PUMP CHARACTERISTICS
RPM 1780 CDS 3015-3
Allowable Operating Region is Shaded
Preferred Operating Region: 70 to 120 % of BEP
Model 3700
Size 4x6-
Imp. Dwg D01048A
Eye Area 33.1 in²
(384mm.) Impeller Dia.
NPSHR
TOTAL HEAD (feet)
TOTAL HEAD (metres)
150HP
125HP
100HP
40HP
CAPACITY
GPM
m³/h
Bottoms Flow Rate: 130 m³/h
NPSHr ~1.5 meters
NPSHa ~3.5 meters
Goulds Serial # Q241C563
Customer: Sepco, Ind./Ok. City
P.O. # 3238367-00
Pump Item No.# PUMP
Service: VARIOUS

Observations during troubleshooting

- Cavitation did not occur at lower operating column pressures
- For the same pressure (27.6 bara),
  - the cavitation did not occur at low boiling rates (low vapor rates)
  - Cavitation did not occur at low liquid circulation rates



Downcomer Choke Flood



Courtesy of Mark Pilling from Sulzer

SYSTEM PHYSICAL PROPERTIES

- iC4iC4/nC4 system main physical properties

Systems	Density Difference, $(\rho_l-\rho_v)$	Density Ratio, ρ_v/ρ_l	Surface Tension
165 psia (11.4 bara)	28.6 lb/ft^3 (458 kg/m^3)	0.06	5.10
300 psia (20.7 bara)	23.0 lb/ft^3 (368 kg/m^3)	0.14	2.15
400 psia (27.6 bara)	17.5 lb/ft^3 (280 kg/m^3)	0.25	0.85

Hypothesis

- Cavitation in the bottom pump was probably caused by the similar mechanism as what caused tray downcomer choking
- Or the cavitation was caused by vapor entrainment

Test & Solution

- Operating the kettle reboiler away from the conditions at which vapor entrainment may occur by reducing the reboiler circulation rate and vapor loading
- Increasing the size of the outlet of the reboiler bottom flow

Lesson Learned

- Kettle reboiler may behave like a tray, not only on mass transfer but also on hydraulics
- Vapor inside the kettle reboiler may not always flow upwards
- The vapor downward entrainment may result in pump cavitation type of problems

Closing Remarks

- Hydraulic problems with the kettle reboiler could be caused by the heat transfer limitation
- For high pressure distillation applications, the kettle reboiler may encounter the same vapor and liquid disengagement problem that is commonly found in a distillation trayed column
- As always, expected the unexpected

Thank you for your attention!