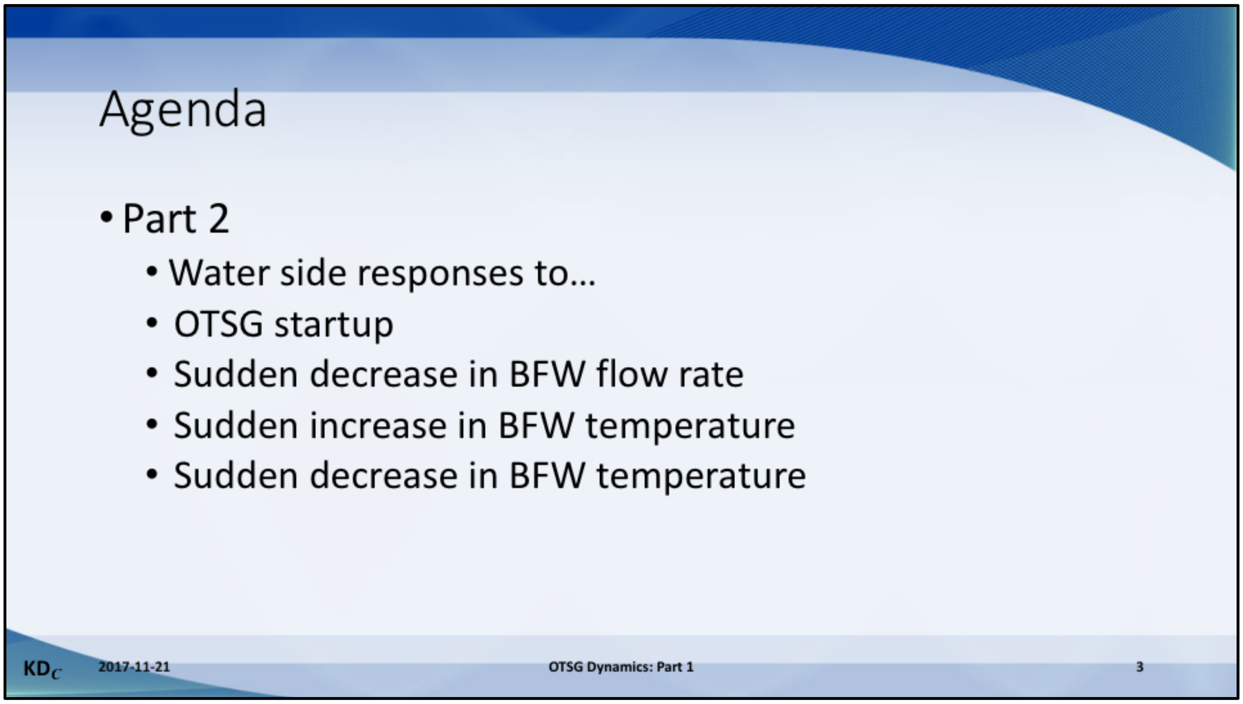
PhD in Fluid Mechanics (modelling)
18 years as a consultant, 10 years experience with SAGD.
Some understanding of drum boiler operation and control.
Extensive troubleshooting of SAGD water hammer issues
Problems originate from the OTSG: Why?

Understand the root cause of operating problems
Understand OTSG dynamics by applying good modelling

Agenda

- Part 1
  - Introduction
  - Review of Drum Boilers
  - Overview of OTSG Layout
  - Venturi steam quality measurement
  - Basic physics for OTSG water side
  - Water side dynamics walkthrough


Agenda
• Part 2
• Water side responses to…
• OTSG startup
• Sudden decrease in BFW flow rate
• Sudden increase in BFW temperature
• Sudden decrease in BFW temperature
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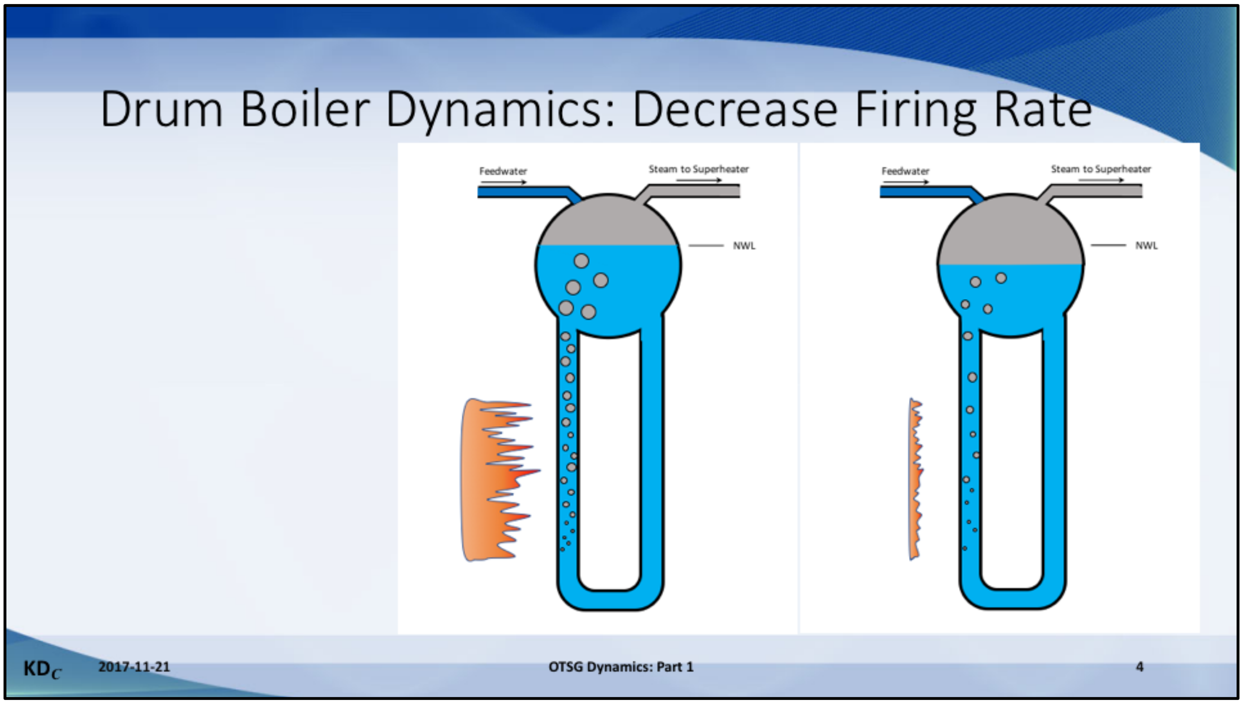


Let’s begin with a quick review of Drum Boilers.

All Power Engineers are familiar with the water side behaviour of drum boilers.
The dynamics of the water level in a drum boiler is dominated by a phenomena that is called Shrink and Swell.
It is this phenomena that make steam drum level control so interesting.

Consider this sketch of a drum boiler with heat added to the risers.
Steam is created, and makes bubbles in the risers. The bubbles in the risers occupy a certain amount of volume. The drum level is held constant at the normal level, and the supply of feed water into the drum equals the flow rate of steam that is produced.
Then, we decrease the firing rate. This makes less steam, and there are now less steam volume in the risers. Water in the drum accumulates in the rises, and the drum level “shrinks”.

Drum Boiler dynamics are well understood

- Changes in firing rate causes changes in liquid volume in risers, and changes the drum level. This is ”Shrink” and “Swell”.

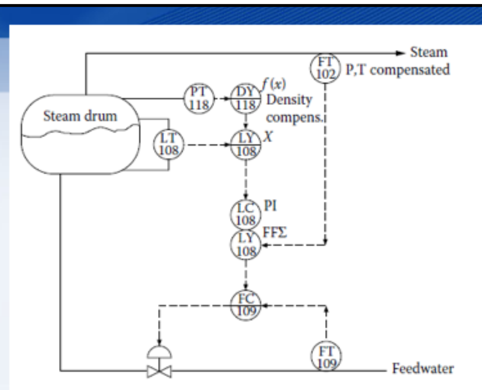
- Another common disturbance is a sudden drop in the feedwater temperature.
  - This causes a sudden quenching of the steam drum, and interrupts the steam production. With a sudden drop of steam flow to the superheater section, the steam temperature exiting the superheater can become very high.

This understanding of drum level dynamics has lead to standard, sophisticated control systems to manage drum level during firing rate changes

- Single element
- Two element
- Three element

The result is that drum boilers are very reliable and do not experience spurious trips.
- A drum boiler is expected to trip maybe once a year, and this is due to an actual mechanical or instrument failure, and must be fixed.

Student Question



- Suppose we are operating a Drum Boiler with a good 3-element level control setup
  - Level control is tuned VERY fast to maintain setpoint, no sloshing
  - What happens if the steam demand decreases?

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This could arise if a well-meaning Process Control person says “I can make that faster”.

Sudden decreasein steam demand causes pressure to increase.
Less boiling in tubes. More water held up in risers.
Drum level drops.
The super fast level control adds a big shot of cold water and quenches the drum.
Kill the steam production. Less steam through superheater, cook the superheater.

This is why we need to understand when things are operating properly.

Oilfield OTSG Configuration

- Typical Conditions
- Wet steam, 75 – 80% quality
- Pressure 8,000 – 10,000 kPag
- Firing rate 50 – 250 MMBTU/hr
- BFW feed rate 50 – 150 t/h
- Water quality 8000 ppm TDS

Innova OTSG

Really awful water. Looks like tea.

Oilfield OTSG Configuration

Innova OTSG

- 4 or 6 tube passes are common
- Convection section
- Horizontal radiant section
- Radiant ~65 ft long

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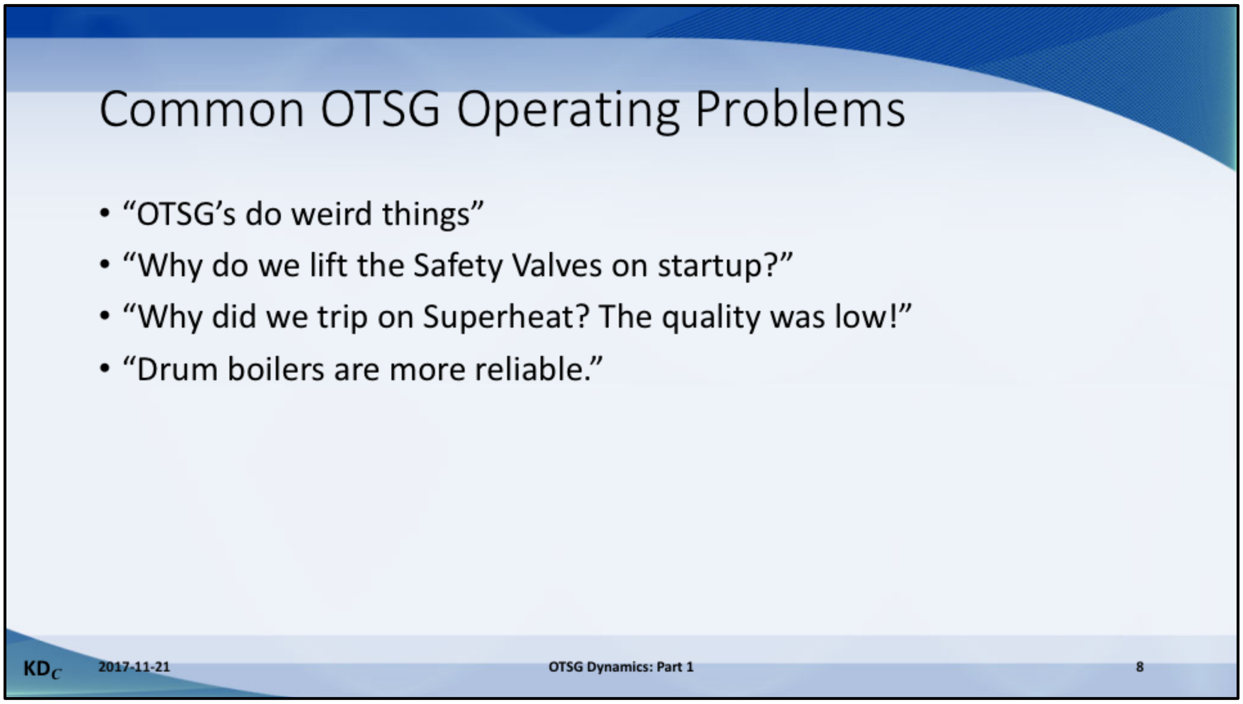
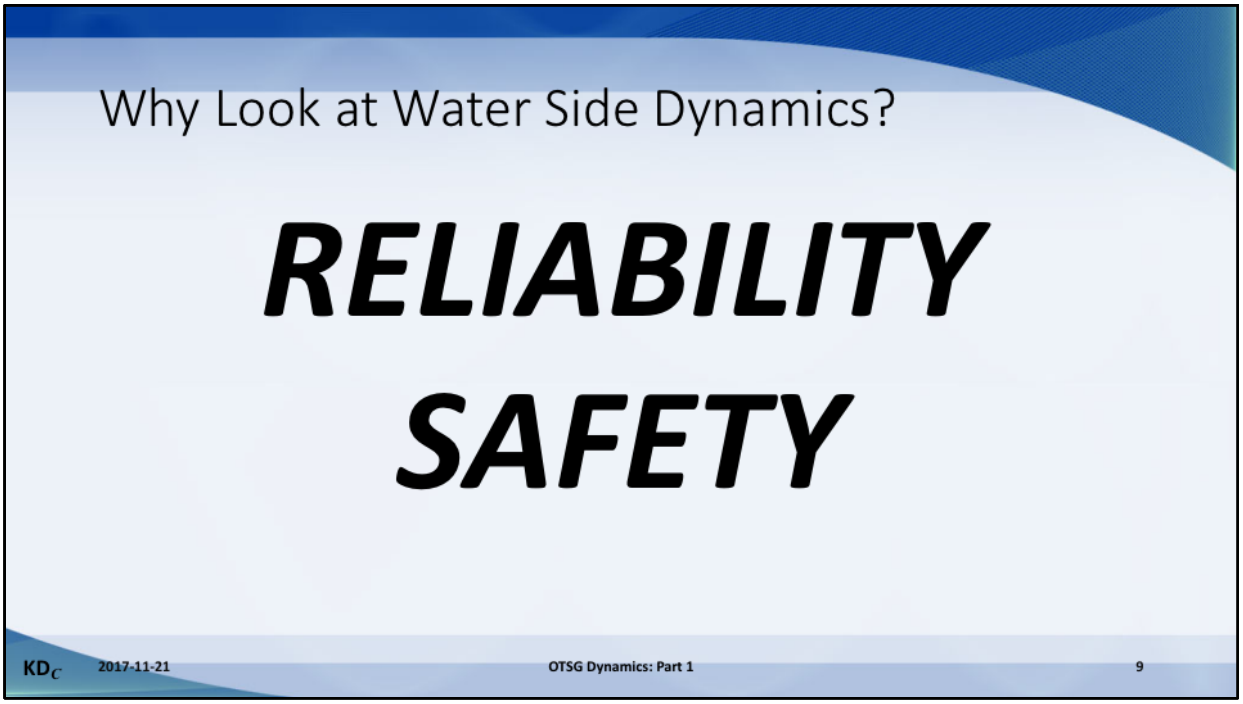
4 or 6 pass is common
250 MMBTU, 150 t/h water rate is common for the large units.
70 MMBTU/h for the smaller units around Lloydminster.

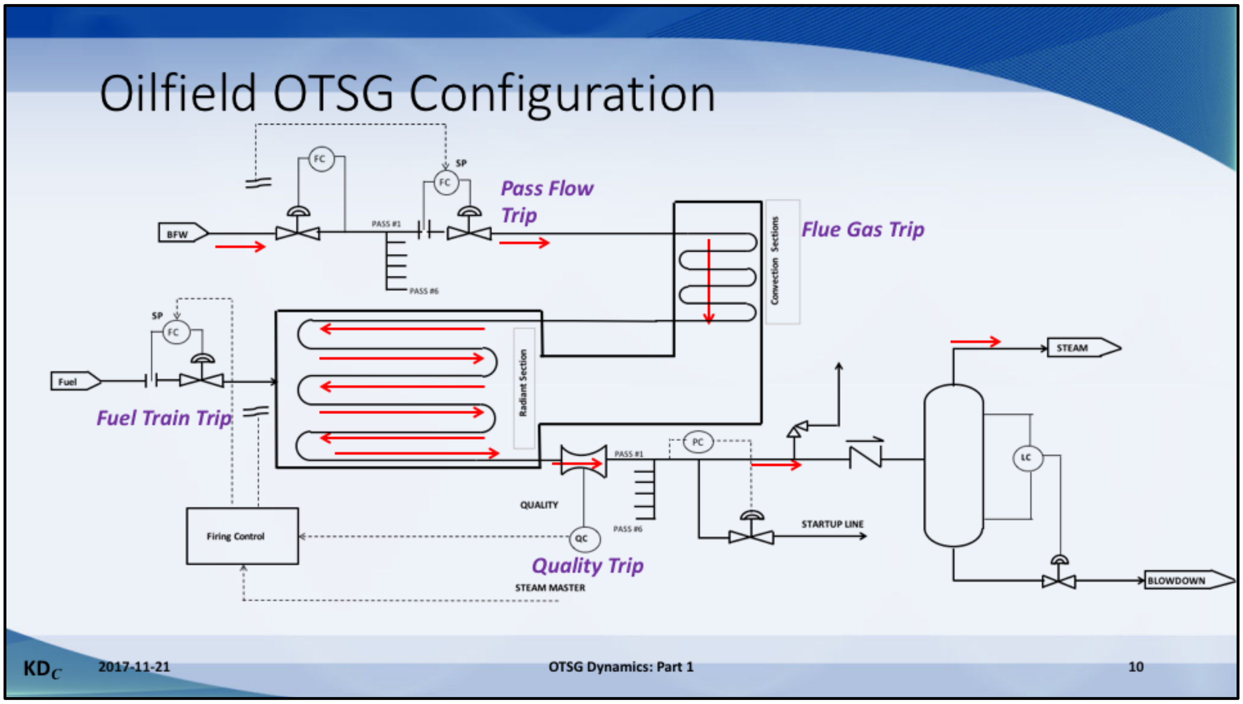


I have heard a few common frustrations in SAGD control rooms. Operations teams feel that OTSGs seem to do some weird things.
Some teams have seen safety valves routinely lift on startup.
Others have seen the odd trip on superheat, but the measured steam quality was low.
Most of the Operations teams have experience with drum boilers. I have heard that drum boilers are considered to be more reliable.



RELIABILITY and SAFETY. Pure and simple.
Yeah, higher steam quality is nice, and worth a fair bit.
I think reliability can also improve by understanding the water side.
But if you can run like hell and relight the OTSG in 3 minutes, without checking why it went down, you can be back in business in 15 minutes. Loss of production is trivial.
But relights are hazardous. Thankfully, I have not seen a lot of serious problems (yet).

If we understand how the OTSG behaves, then we can expect to operate it in a safer manner, and we can expect to control it better for more reliable operation. And increase production rates.
The water side behaviour determines how we should control the feedwater flow rate and the firing rate. This is why it is valuable to understand the water side behaviour of an OTSG.



This is a schematic for an OTSG.

One valve to control the total flow of water. Then pass balancing valves.
Wind down through the convection section, and get warmer. Boiling starts at the exit of the convection section. Then a few laps back and forth across the radiant section.

Make about 78% quality steam. Wet steam flows through the pass venturi, which measures a pressure drop and calculates the steam quality. Then the passes combine.

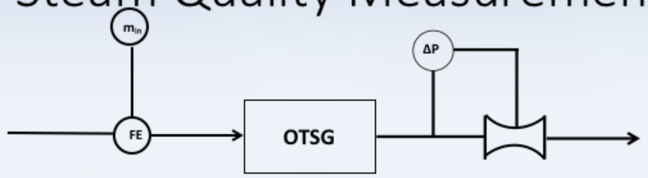
Normal flow is through a check valve and to a separator vessel, with the steam going to the well pad and hot blowdown used to preheat BFW in a heat exchanger. Startup path is through a control valve, and then towards a pond or tank.

There are a number of trips that are often present.
On the water side, Pass Flow deviation is a frequent trip in several operating plants.
Steam quality trips are less common now than they were a few years ago.
On the fire side, low O2 or high combustibles in the flue gas is a common trip.

On the firing train, Low fuel gas supply pressure is a common trip that prevents reliable light-off.

The control system is often very complex, and there are several PID controllers that can fight with each other (ie, pass flow control and the total BFW flow control).

Venturi Steam Quality Measurement



$$\rho_{out} = \frac{1}{\Delta P}\left(\frac{m_{in}}{K}\right)^2 \qquad m_{out} = K\sqrt{\rho_{out}\,\Delta P}$$

Sometimes $m_{out} \neq m_{in}$
Venturi quality reads false

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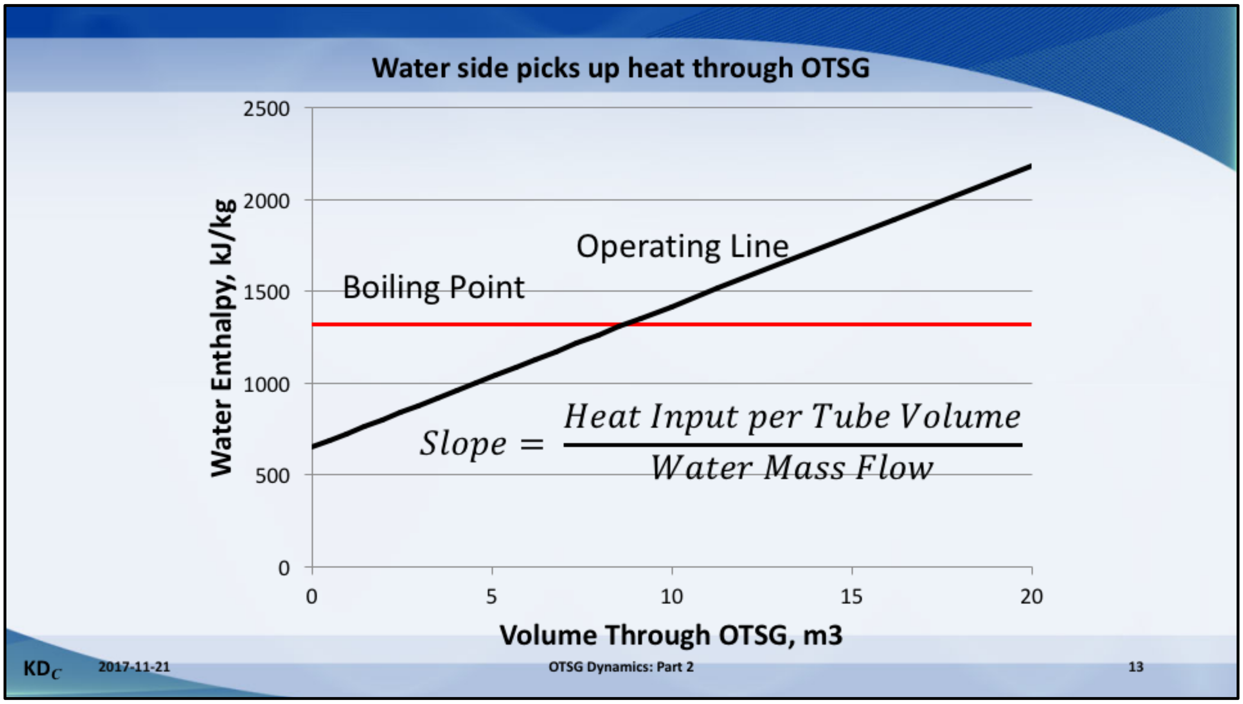
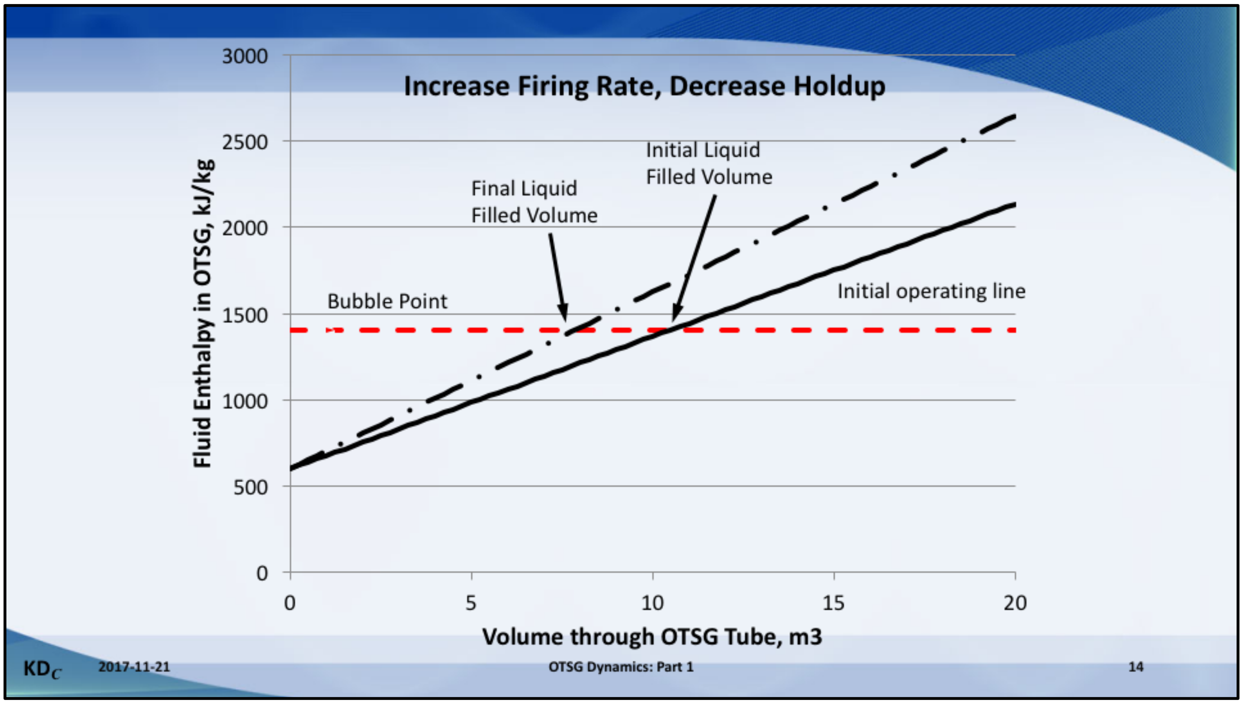
In general, if something causes the mass flow out of the tube to be different from mass flow in (or, there is water accumulation) then the steam quality venturi reads false.

Basic Physics of OTSG Water Side

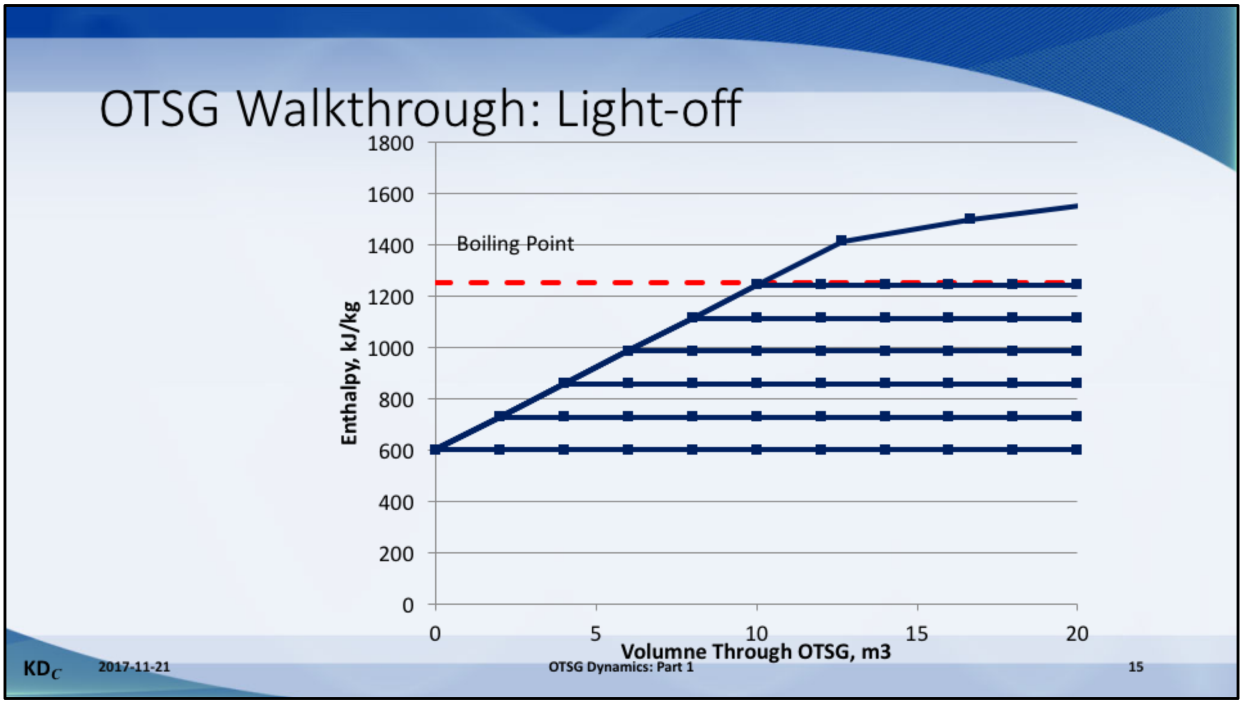
- More like a pipeline than a drum boiler
- Water flows through the tubes
- As water moves through the tubes, heat is picked up from the fire side
- As heat is picked up, water expands a tiny bit
- At some point, water is hot enough to boil and expands **A LOT**



Highlight the water volume in the OTSG. This is THE most important concept for an OTSG.
The time needed to go through the liquid section as the second most important concept.



Highlight how the liquid filled volume changes.



Explain that everyone goes one step forward, one over.
Cross the saturation line and expand.

Agenda

- Part 1
- Part 2: Water side responses to…
  - OTSG startup
  - Sudden decrease in BFW flow rate
  - Sudden increase in BFW temperature
  - Sudden decrease in BFW temperature

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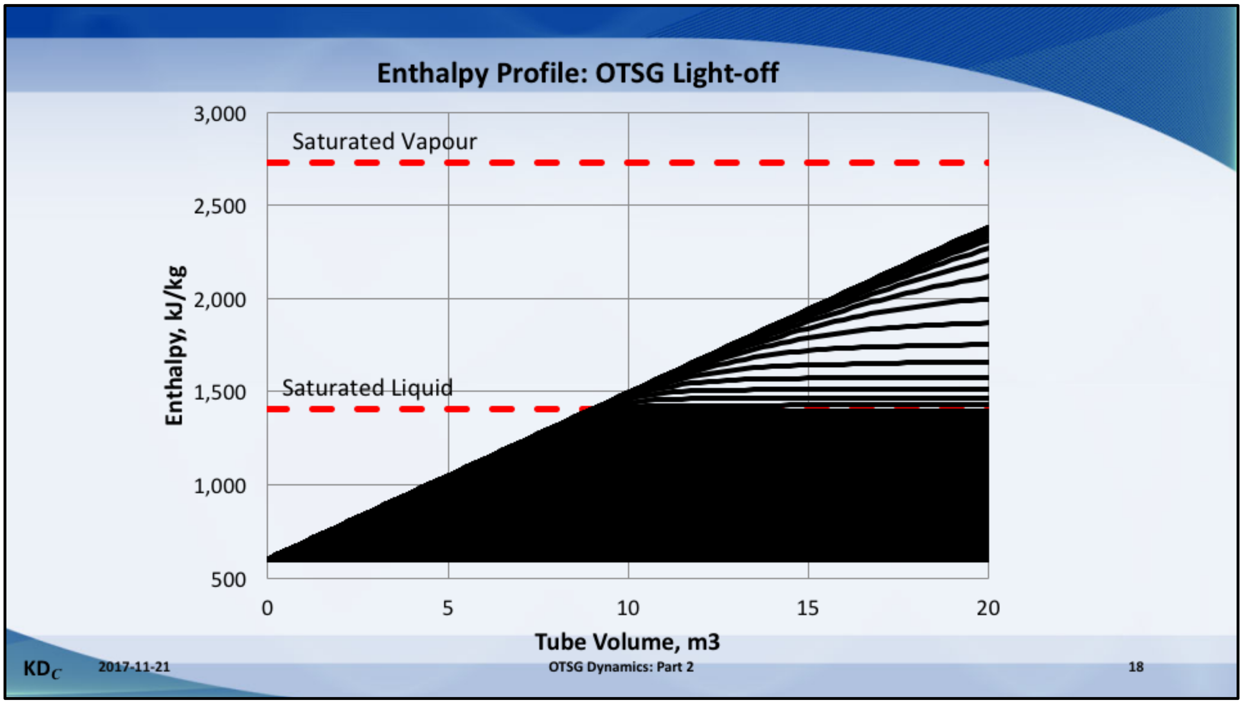
Welcome to Lecture 2.
I will show you what goes on inside the OTSG tubes, and share some observations.

OTSG Light-off

- OTSG is started with firing rate at a minimum
- BFW flow rate is set to get normal steam quality
- Routed to a startup line, and pressure is maintained with a valve

- PSVs sometimes lift during startup
- Pipe movement on the startup line
- How can we avoid problems?


Enthalpy Profile: OTSG Light-off
3,000
2,500
2,000
1,500
1,000
500
Enthalpy, kJ/kg
Saturated Vapour
Saturated Liquid
0
5
10
15
20
Tube Volume, m3
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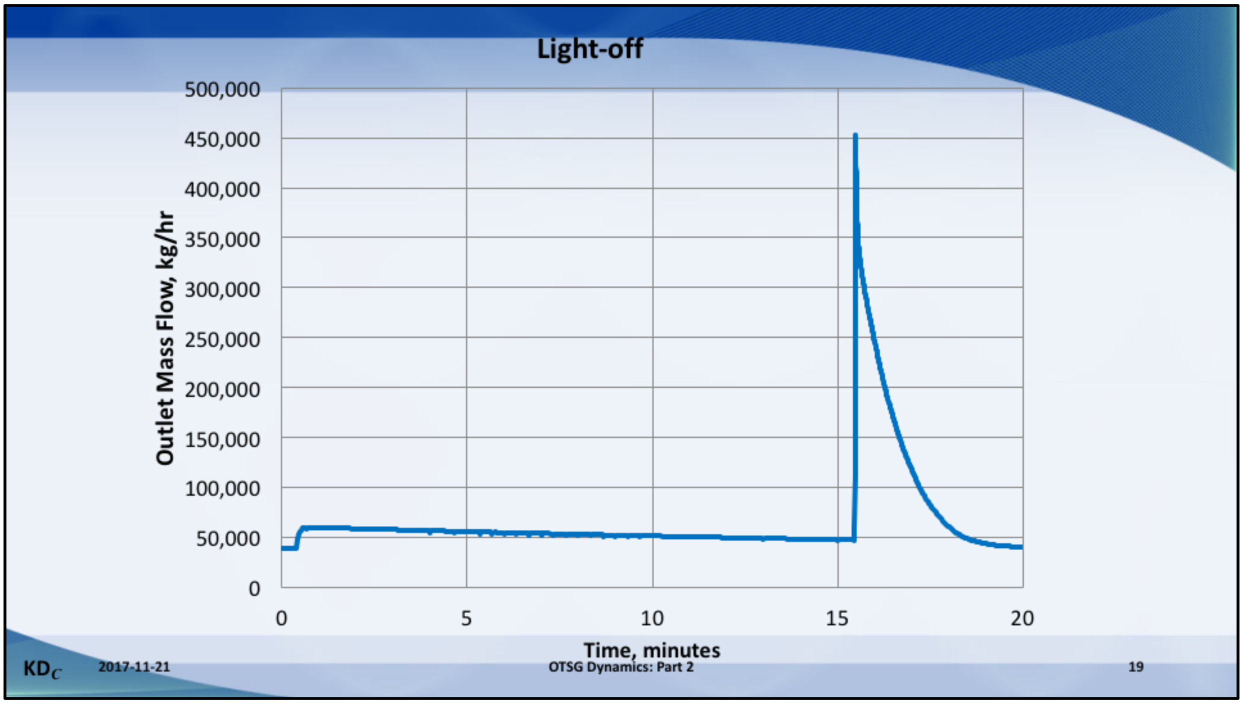
No face shot

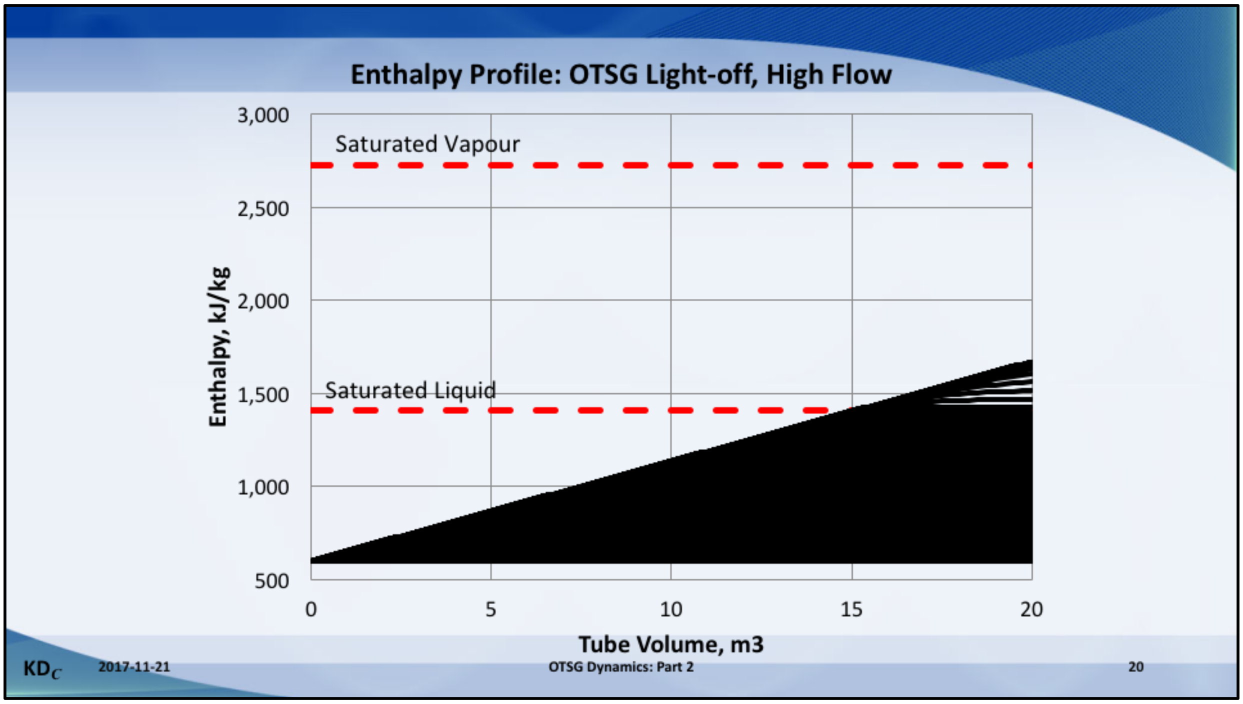


The sudden increase in outlet flow rate is a reflection of the added heat decreasing the mass of water in the tubes, and forcing water out.
Then the radiant section boils all at once and there is a huge Exodus out of the tubes.

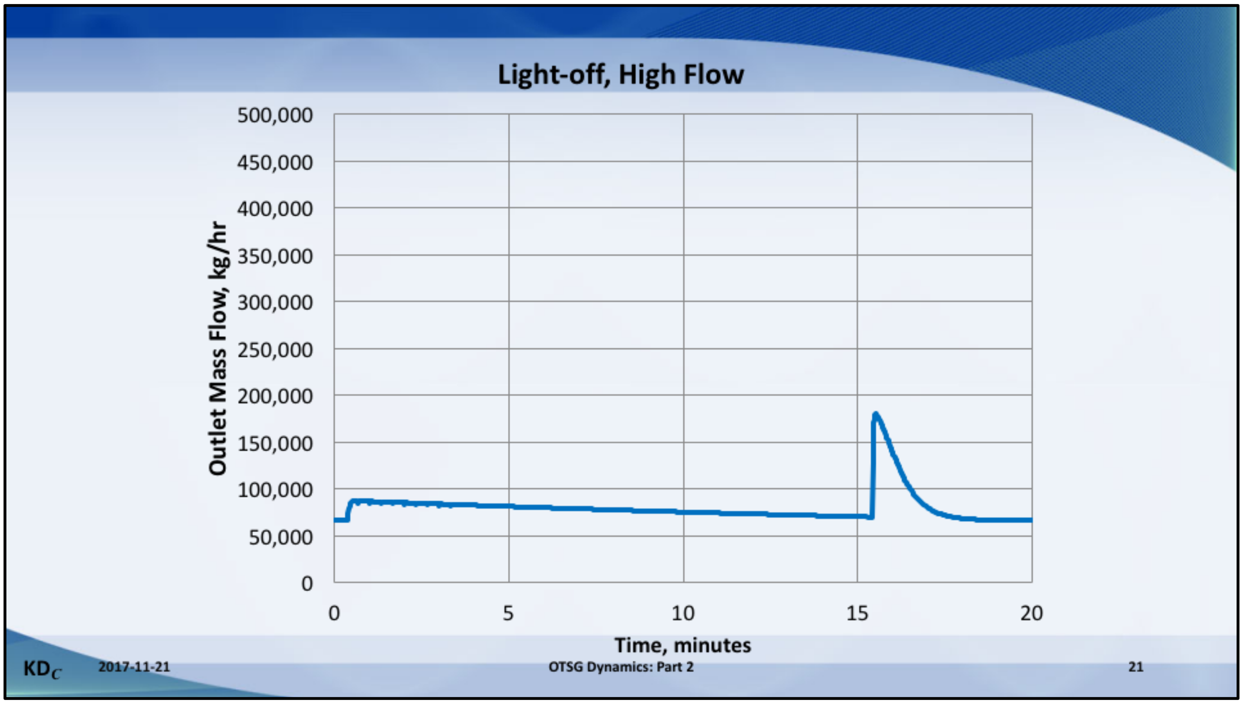
The entire radiant section boils all at once. Think about our favourite joke involving two cold beer, and an unsuspecting friend. Bonk the bottle, and a quarter of the beer gushes out.

This causes the pressure to build in the OTSG because it is difficult to get the large mass of water through the startup valve. And the PSV may lift.
On one OTSG startup, the pressure was held at 8000 kPag. When the temperature reached boiling, the pressure shot up to 11,000 kPa, just short of the PSV set pressure 11,700 kPa.
It did not lift the PSV this time. Hot showers were common.

That's great. What can we do about this? Remember, we are already at the lowest stable firing rate that we can get.



OTSG startup without the huge rush of water.
Higher water flowrate, cross the boiling point further down the tubes. Less water is kicked out when everything boils.



The steady state flow rate out is higher, but the peak is much smaller. The startup control valve will have a much better chance of providing enough capacity to keep the OTSG pressure below the PSV set pressure.

- Common practice is to start the OTSG at higher flow rates

Decrease BFW Flow Rate

- Often caused by turning off a spare pump
- Or another OTSG is robbing some water

- We see a sudden increase in measured steam quality (problem?)
- But the Separator Level drops slowly
- How can we explain both observations?

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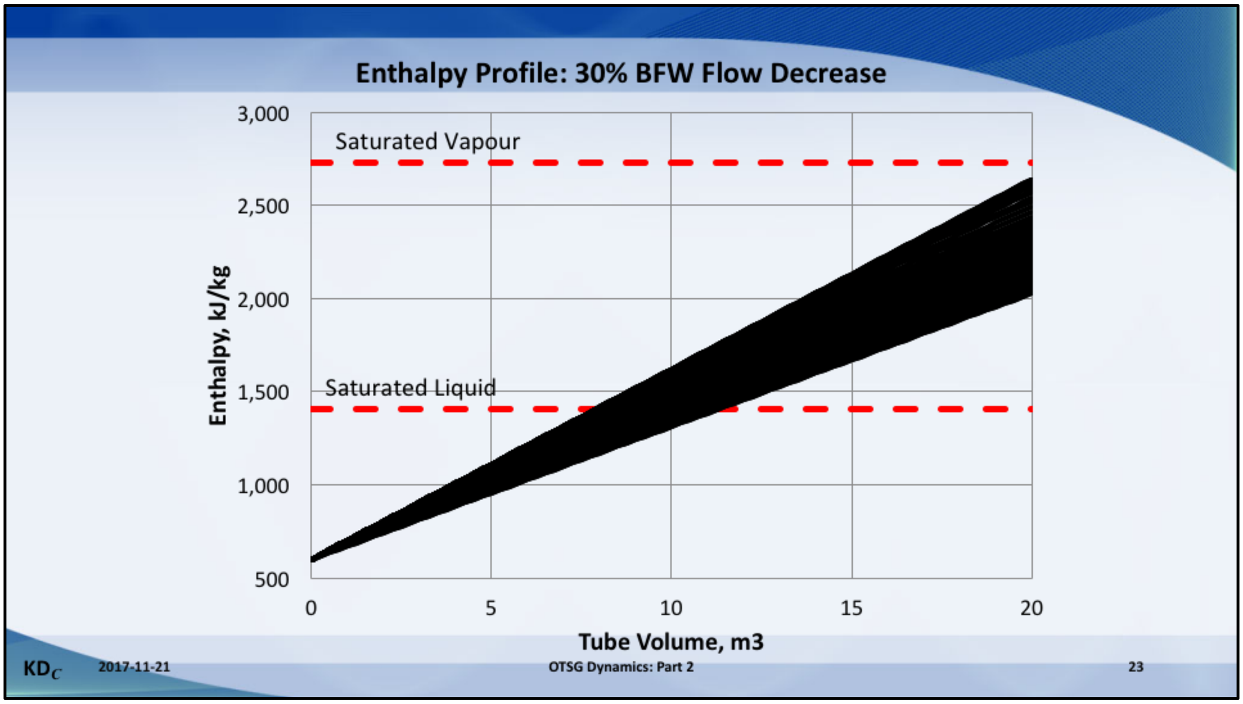
Enthalpy Profile: 30% BFW Flow Decrease
Saturated Vapour
Saturated Liquid
Enthalpy, kJ/kg
3,000
2,500
2,000
1,500
1,000
500
0
5
10
15
20
Tube Volume, m3
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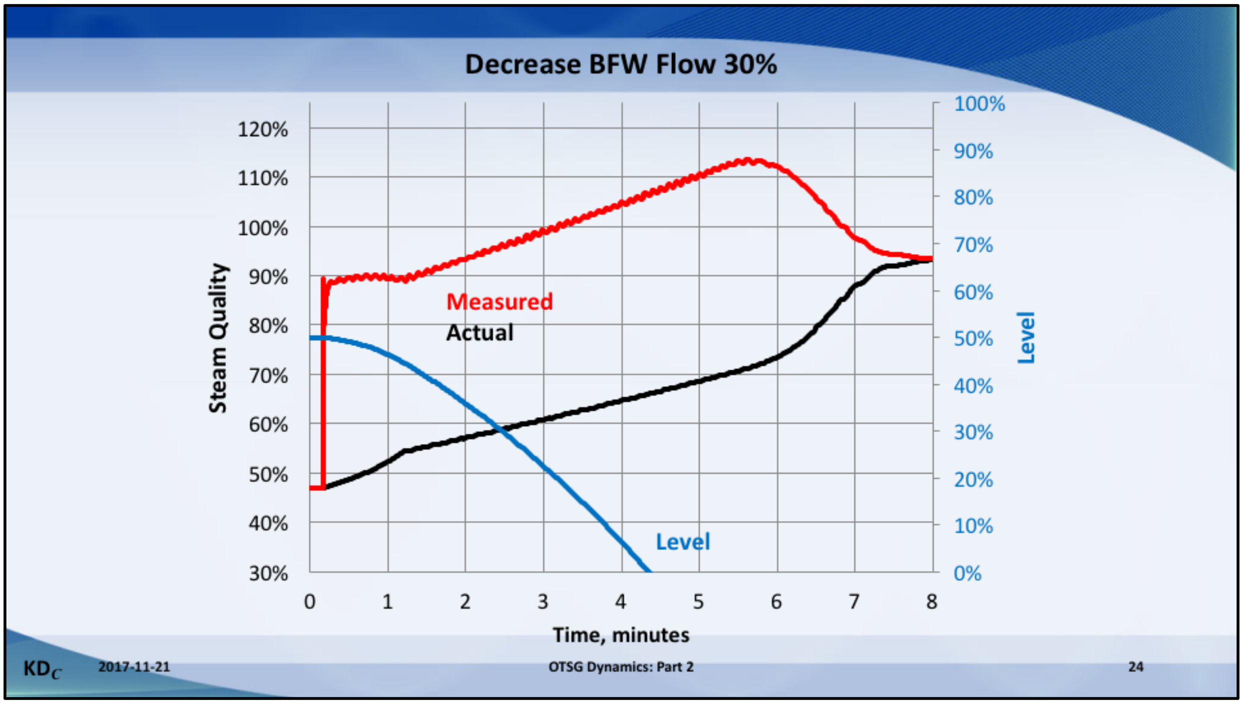
This is SLOW



- Sudden drop in BFW flow rate causes outlet enthalpy to increase slowly
  - The steam quality measurement reads FALSE for 5 - 6 minutes
  - This looks a lot more serious than it really is.
  - Spurious HH quality measurement may cause frequent firing trips
- Consider softening HH quality trips or HH pass flow deviation

Increase in firing rate is nearly identical for change in steam quality

BFW Flow: Implications

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- Sudden water shortage is not as serious as one might think.
- No need to trip the boiler immediately
- Flow controller should open up and get flow back to normal.

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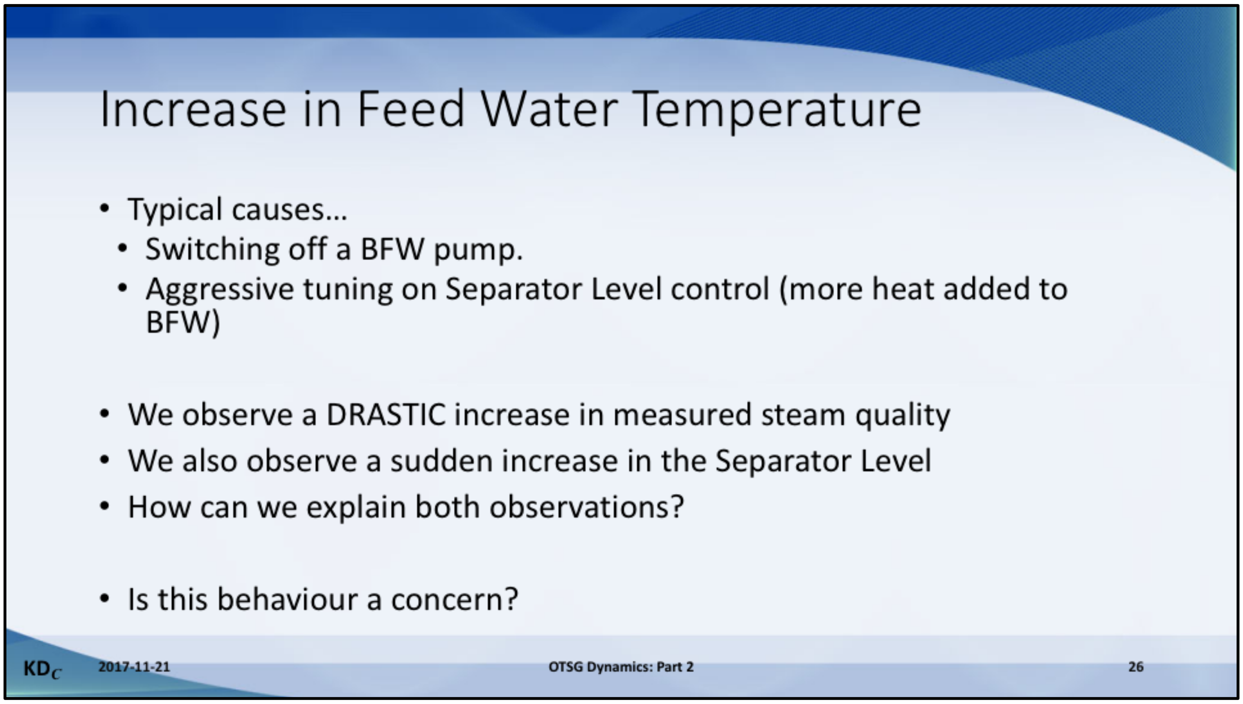
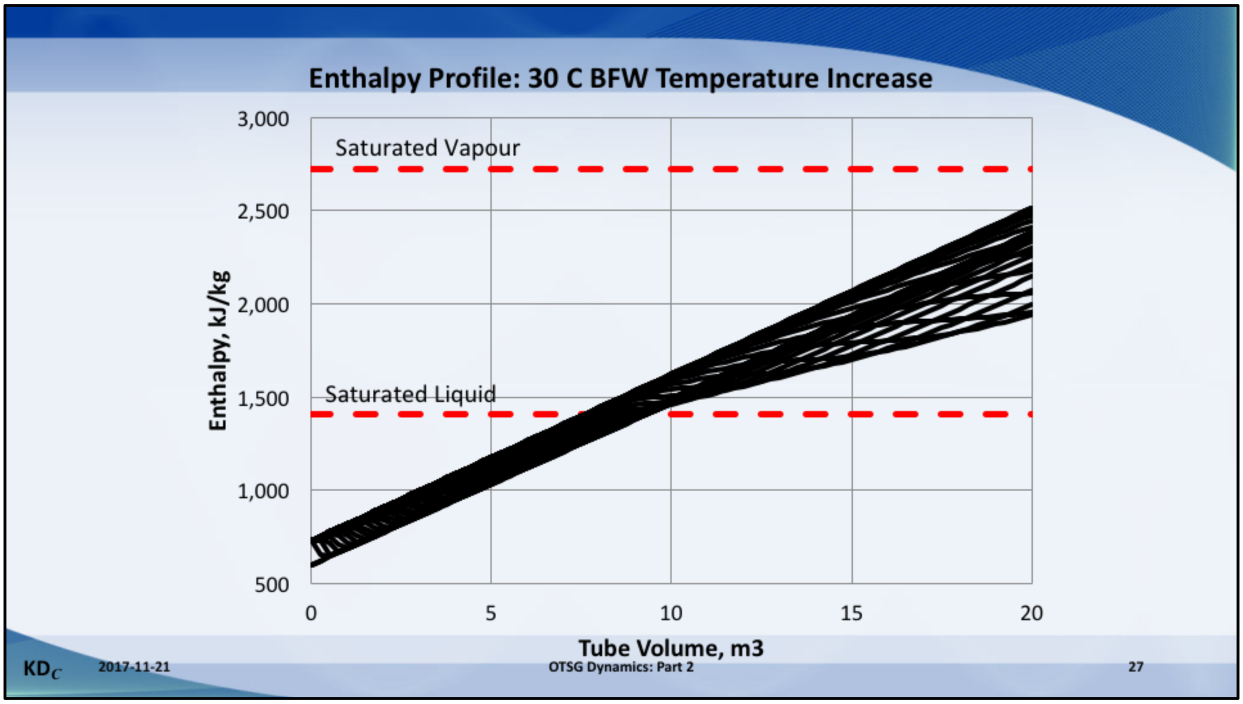
A sudden drop in water flow rate is not a hazard as long as the flow controller can take action.
No different than level control in a drum boiler. Level controller sets the BFW flow setpoint. A blip in the BFW header is managed because the BFW flow is kept on track.

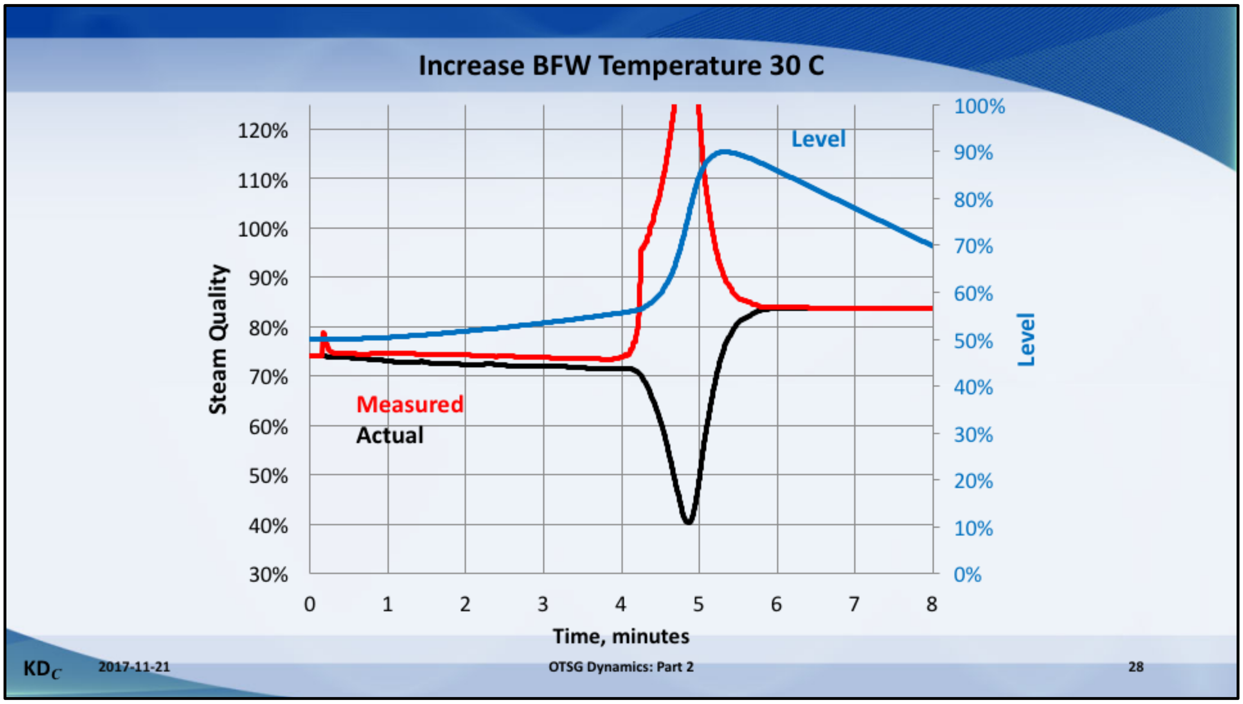


My YouTube lecture demonstrates why a pump start changes the feed water temperature.



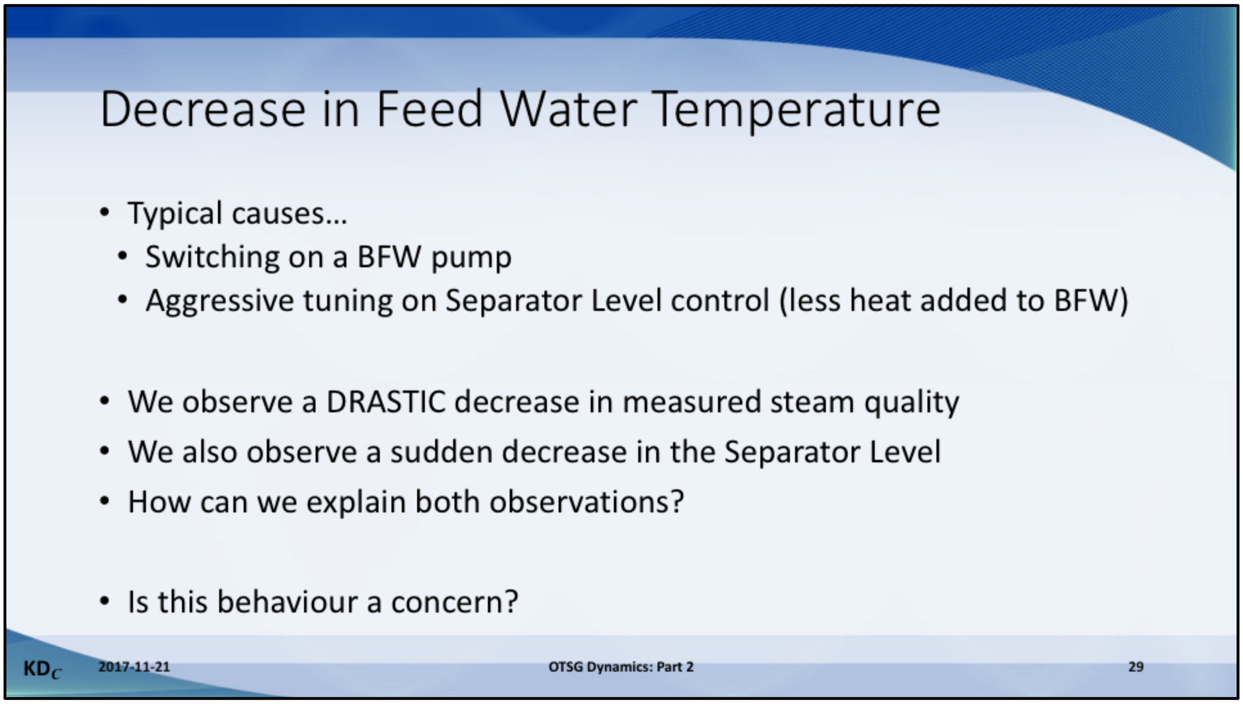
Start with about 150 C feed temperature, or 600 kJ/kg enthalpy.
Then we watch a hot front move through. The hot front spreads out because of the thermal mass of the piping. Steel has to warm up.

Wait for the hot front to barely touch the boiling line. What will happen next?



The actual steam quality drops because a large mass of water is pushed out.
The measured quality increases because the measured DP becomes high for a short time.
The level in the separator jumps up, and then slides down.

This was the key observation that confirmed what is going on inside the OTSG. A 10 C rise in the water temperature caused the separator level to hop up by a meter, then slide down.


Decrease in Feed Water Temperature
• Typical causes…
• Switching on a BFW pump
• Aggressive tuning on Separator Level control (less heat added to BFW)
• We observe a DRASTIC decrease in measured steam quality
• We also observe a sudden decrease in the Separator Level
• How can we explain both observations?
• Is this behaviour a concern?
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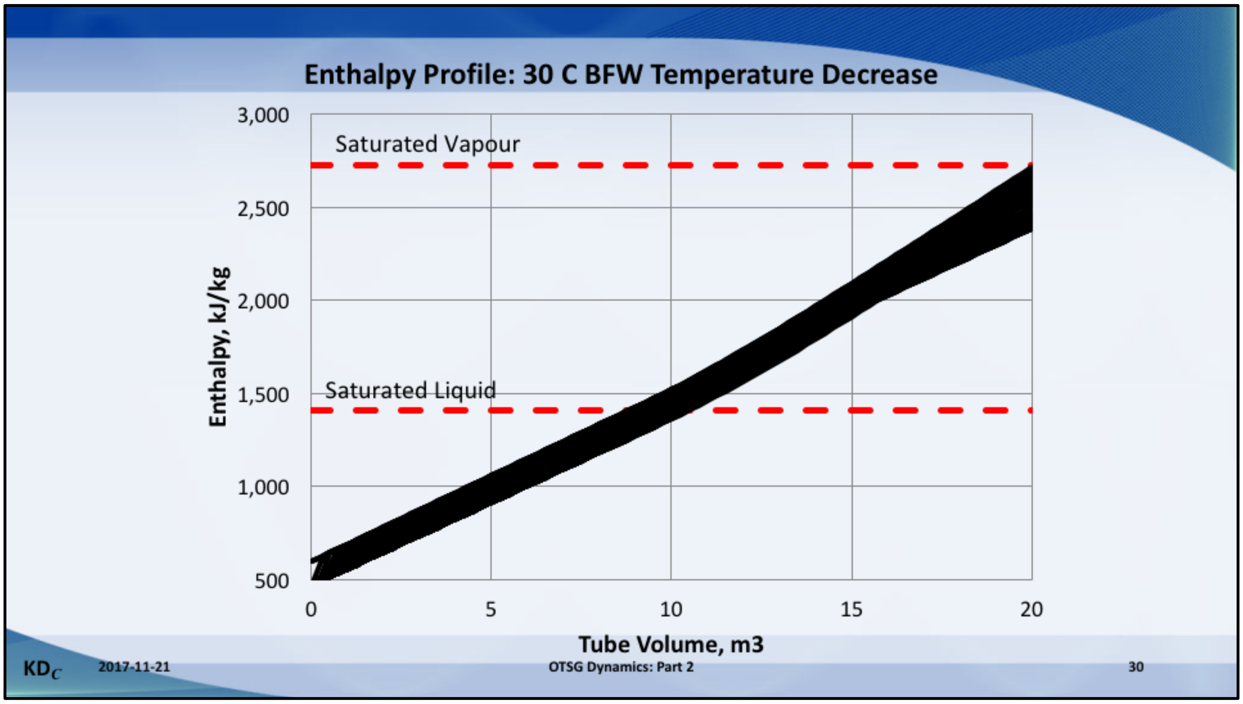
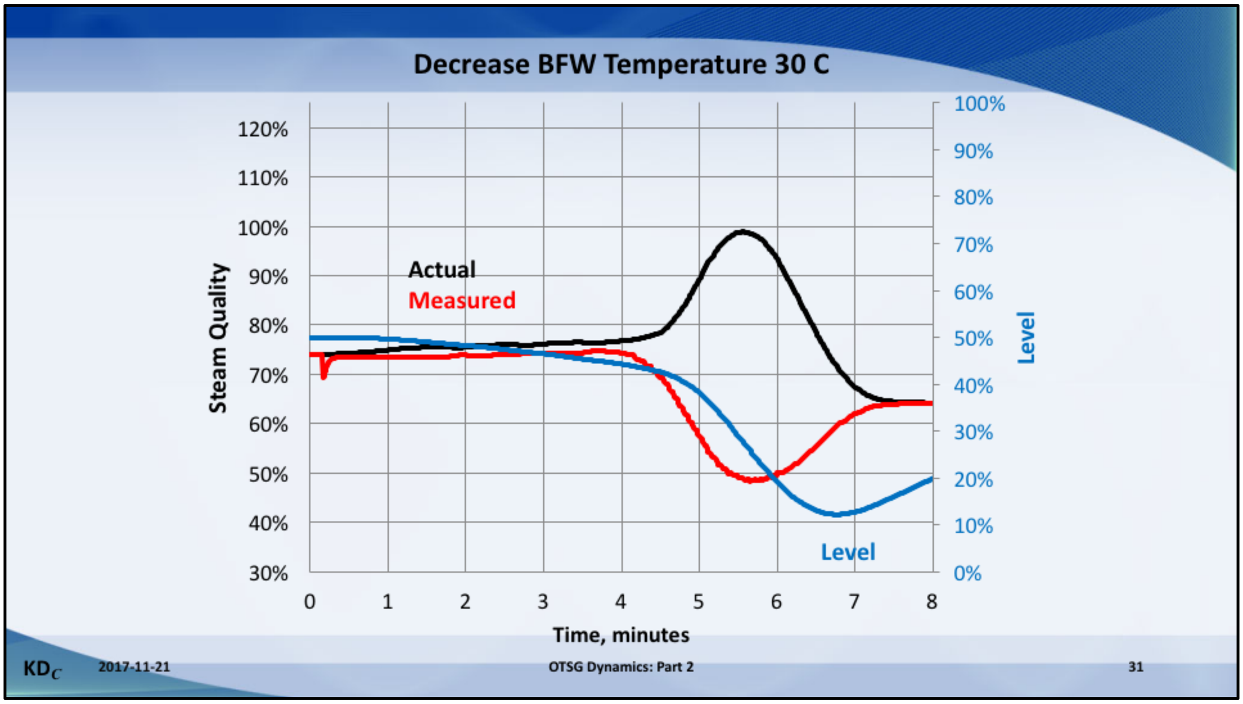
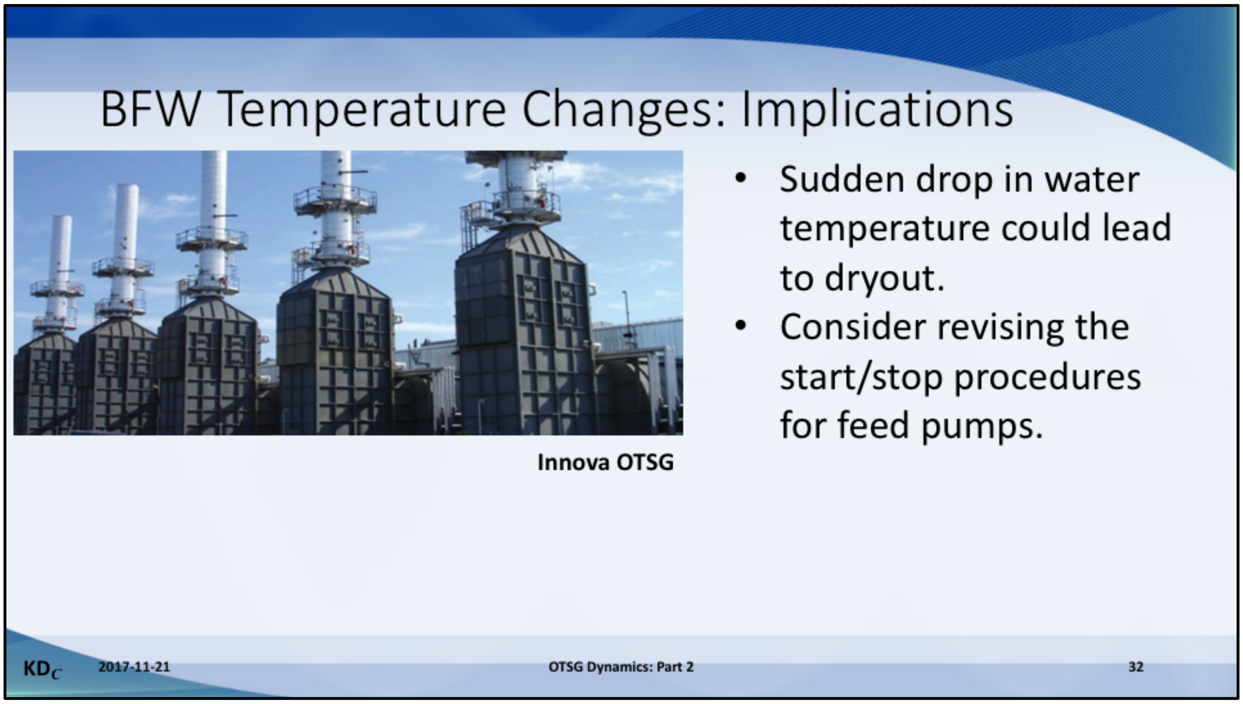


No face shot. There is about 8 m3 of water to start with.
Then there is 10 m3 of water. In between, the OTSG filled with water.
This means that the water flow rate down the tubes decreased during the filling stage.



The measured steam quality drops, but the actual quality increases and may superheat.
The trusted measurement is the drum level. Level crashes about 1 m, then rises slowly.

Another key observation. Some operators have seen superheat associated with this.
Difficult to correlate superheat trip with a drop in water temperature because
a) This is not intuitive,
b) The 5 minute time delay makes it difficult to see the connection.



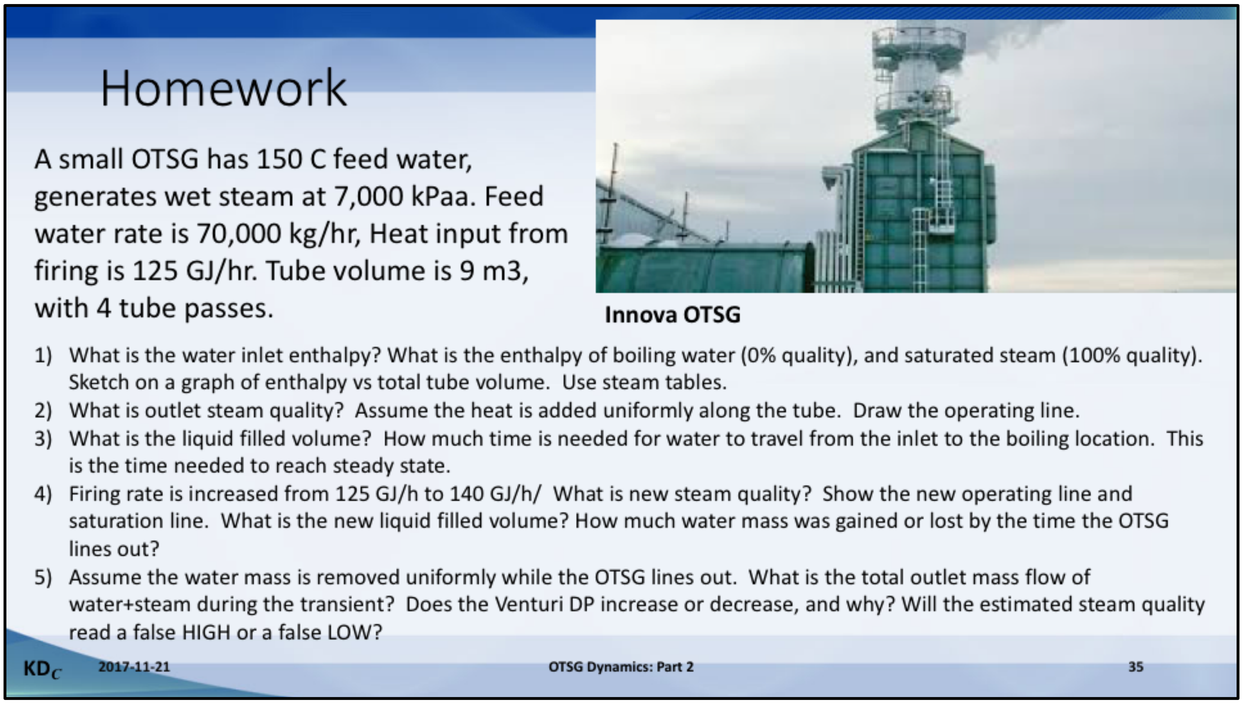
- A drop in temperature could lead to dryout. This needs to be avoided.
- Pay attention to procedures for starting pumps.
- Most OTSG have fairly tight pass flow deviation trips.
- The revised pump start method avoids pass flow trip, but potentially damaging dryout.
- A normal pump start would cause change in water flow (trip), but no change in temperature.
- Softening the pass flow deviation trip would permit the normal pump start, and avoid dryout.

Summary of OTSG Water Side Dynamics

- OTSG water side dynamics are dictated by changes in liquid volume held in the tubes. Similar to Drum Boiler shrink and swell.
- Everything plays out over 3 - 5 minutes.
- This is the time needed to flow though the liquid filled section

Summary: Operating Tips

- Start OTSGs at higher BFW rates: less surge to manage
- Consider softening steam quality alarms and trips
- Find root cause of rapid BFW temperature changes
  - Look for procedural changes to avoid temperature bumps
  - Can you tolerate slower controller tuning?



A small OTSG has 150 C feed water, and generates wet steam at 7,000 kPaa. Feed water rate is 70,000 kg/hr, Heat input from firing is 125 GJ/hr. Tube volume is 9 m3, with 4 tube passes.

1) What is the water inlet enthalpy? What is the enthalpy of boiling water (0% quality), and saturated steam (100% quality). Sketch on a graph of enthalpy vs total tube volume. Use steam tables.
2) What is outlet steam quality? Assume the heat is added uniformly along the tube. Draw the operating line.
3) What is the liquid filled volume? How much time is needed for water to travel from the inlet to the boiling location. This is the time needed to reach steady state.
4) Firing rate is increased from 1125 GJ/h to 140 GJ/h/ What is new steam quality? Show the new operating line and saturation line. What is the new liquid filled volume? How much water mass was gained or lost by the time the OTSG lines out?
5) Assume the water mass is removed uniformly while the OTSG lines out. What is the total outlet mass flow of water+steam during the transient? Does the Venturi DP increase or decrease, and why? Will the estimated steam quality read a false HIGH or a false LOW?

OTSG Water Side Dynamics

- Kevin Dorma Consulting, Ltd.
- www.kevindorma.ca

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