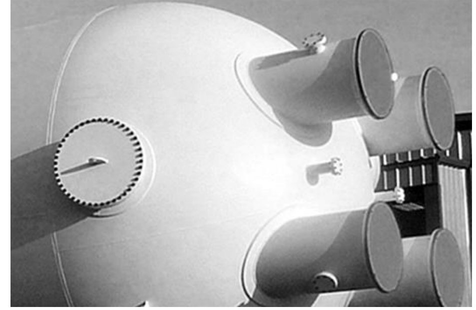


PMAX Cycle Isolation Module

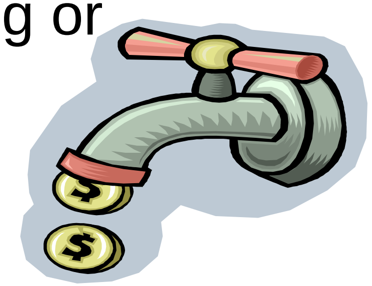
Greg Alder

Background

- What is Cycle Isolation?
- Impact of Cycle Leakages – Heat Rate and Cost
- Identifying and Tracking Leaking Valves
- PMAX Cycle Isolation Calculation Module

Cycle Isolation

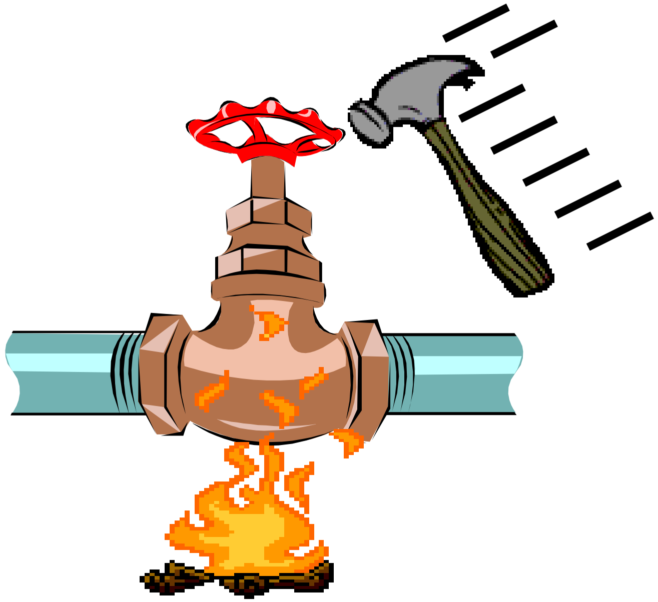
- **Cycle Isolation: Assuring all flows in the cycle are going to the proper destination**
  - Internal Isolation: All flows within the cycle are going to the proper destination.
  - External Isolation: Accounting for all flows entering or leaving the cycle.



- **One of the largest losses at many plants**
- **Losses in excess of 400 Btu/kWh have been documented, losses of 50 to 100 Btu/kWh are common**
- **Diligent O&M can minimize the loss**
  - 20% can be eliminated by checking and closing valves on a regular basis
  - 80% can be eliminated by routine maintenance

Why Are Valve Leaks Common?

- **High temperature and high differential pressure**
- **Severe service**
- **Cycling of the valves open and closed**
- **More of a problem with cycling units**

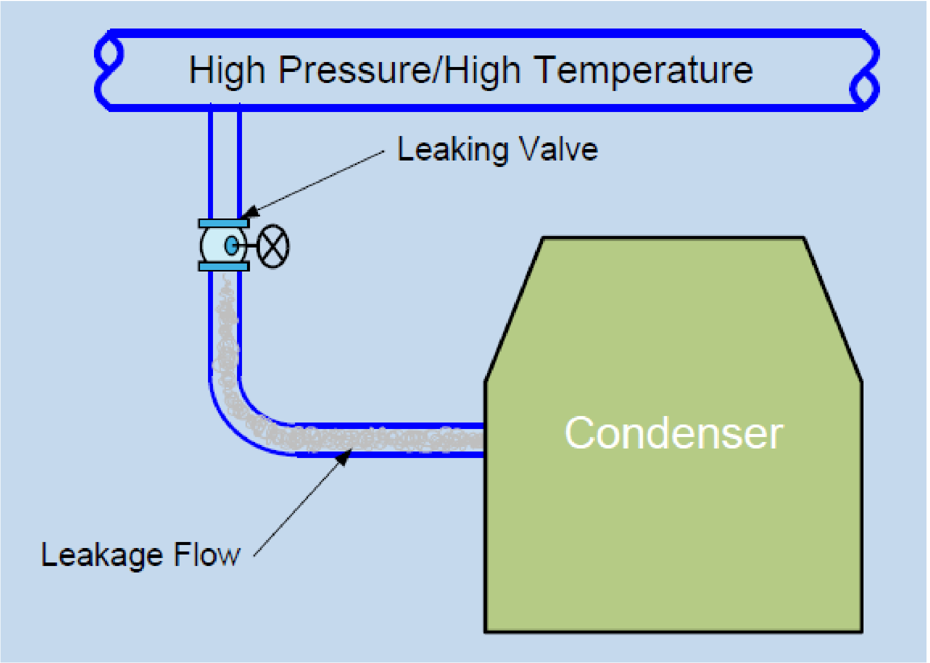


Common Loss Areas

- **Start up drain**
  - Main steam
  - Cold reheat
  - Hot reheat
  - Extraction line
- **Feedwater heaters**
  - Alternate or emergency drains
  - Start up vent
  - Feedwater-side bypass valves
- **Steam seal system**
- **Turbine bypass system**
- **Sootblower thermal drains**
- **Relief valves**
- **Boiler feed pump recircs**
- **Steam drain line orifices (and orifice bypass valves)**
- **Steam traps**

Operational Impact of Cycle Leaks

- **High energy valve leakage leads to:**
  - Increased heat rate
  - Reduced plant efficiency
  - Potential valve damage
  - Reduced generation
  - Increased fuel usage
  - Increased water production cost
  - Increased maintenance cost



Reactor Report – January 23, 2017

Nuclear Plant XYZ was operating at reduced capacity early January 23 to address a steam leak from a valve in the system that is used to increase the efficiency of the steam cycle. The unit was operating at 95% of capacity that morning, down from 100% January 22, according to NRC daily reactor status reports. Power will remain reduced until repairs are completed.

Heat Rate and Cost of Common Cycle Leakages

Location	HR Penalty (Btu/kWh)	Fuel Cost ($/yr)
Main steam startup drain	20	$100,920
Hot reheat startup drain	20	$100,920
#1 Htr E-drain 50% to condenser	56	$282,576
#2 Htr E-drain 50% to condenser	65	$327,990
#3 Htr E-drain 50% to condenser	6.5	$32,799
#5 Htr E-drain 50% to condenser	5.9	$29,771

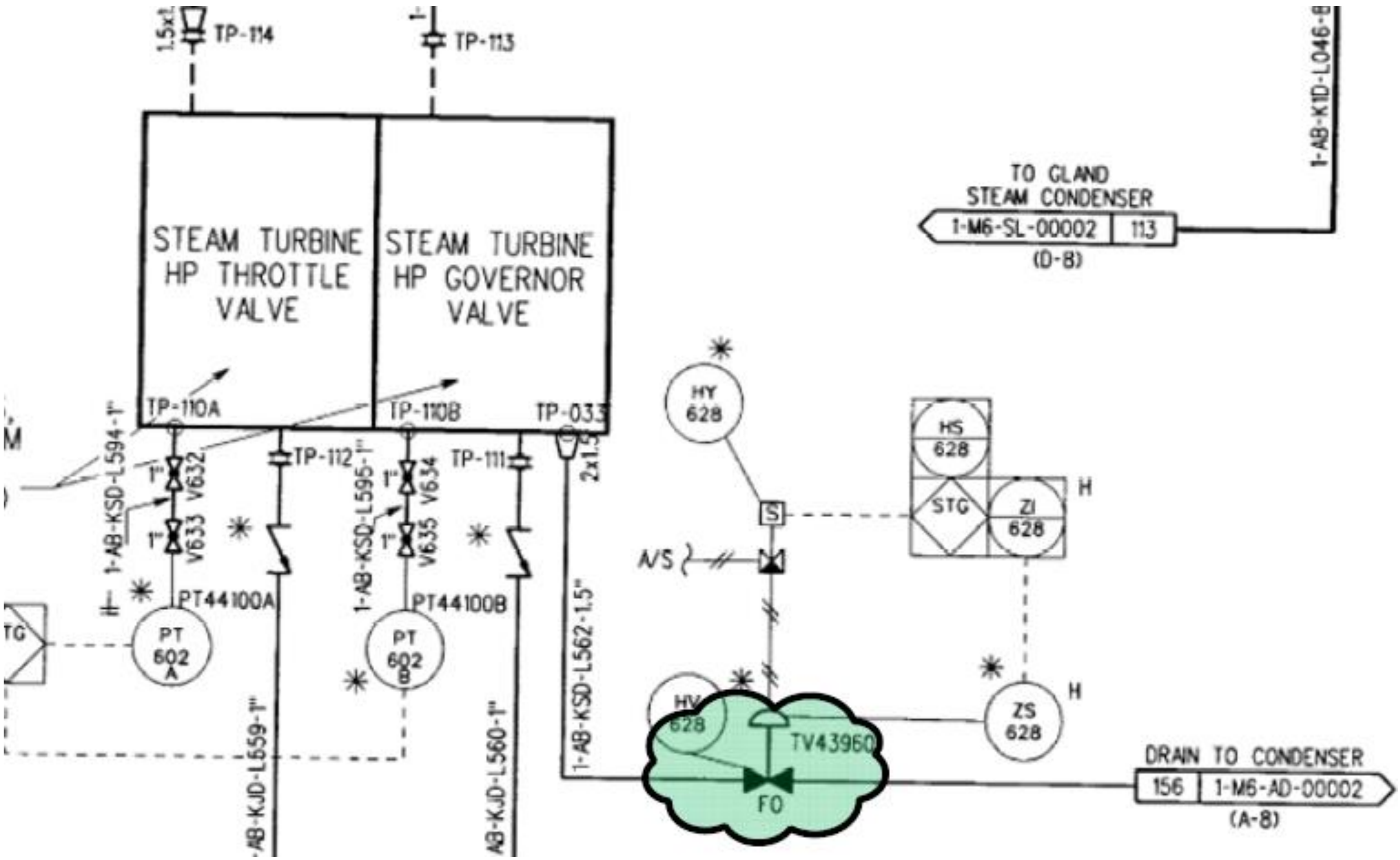
Steps for Cycle Isolation Monitoring

- **Identify Valves to Monitor – P&IDs**
- **Locate the Valves – isometrics & walk down the plant**
- **Determine measurement location**
  - As far downstream of valve as possible (10 l/d or more is best)
  - Measure pipe temperature, not insulation temperature
  - Thermocouple with wires run to remote location, contact pyrometer, or infrared
    - If using infrared insure pipe is not “shinny” and that the hole in the insulation is adequate
- **Establish a walkdown order and frequency**
- **Create a valve list (spreadsheet)**
  - Record date/ valve information and temperatures
- **Establish prioritization or calculation methods for leaking valves**

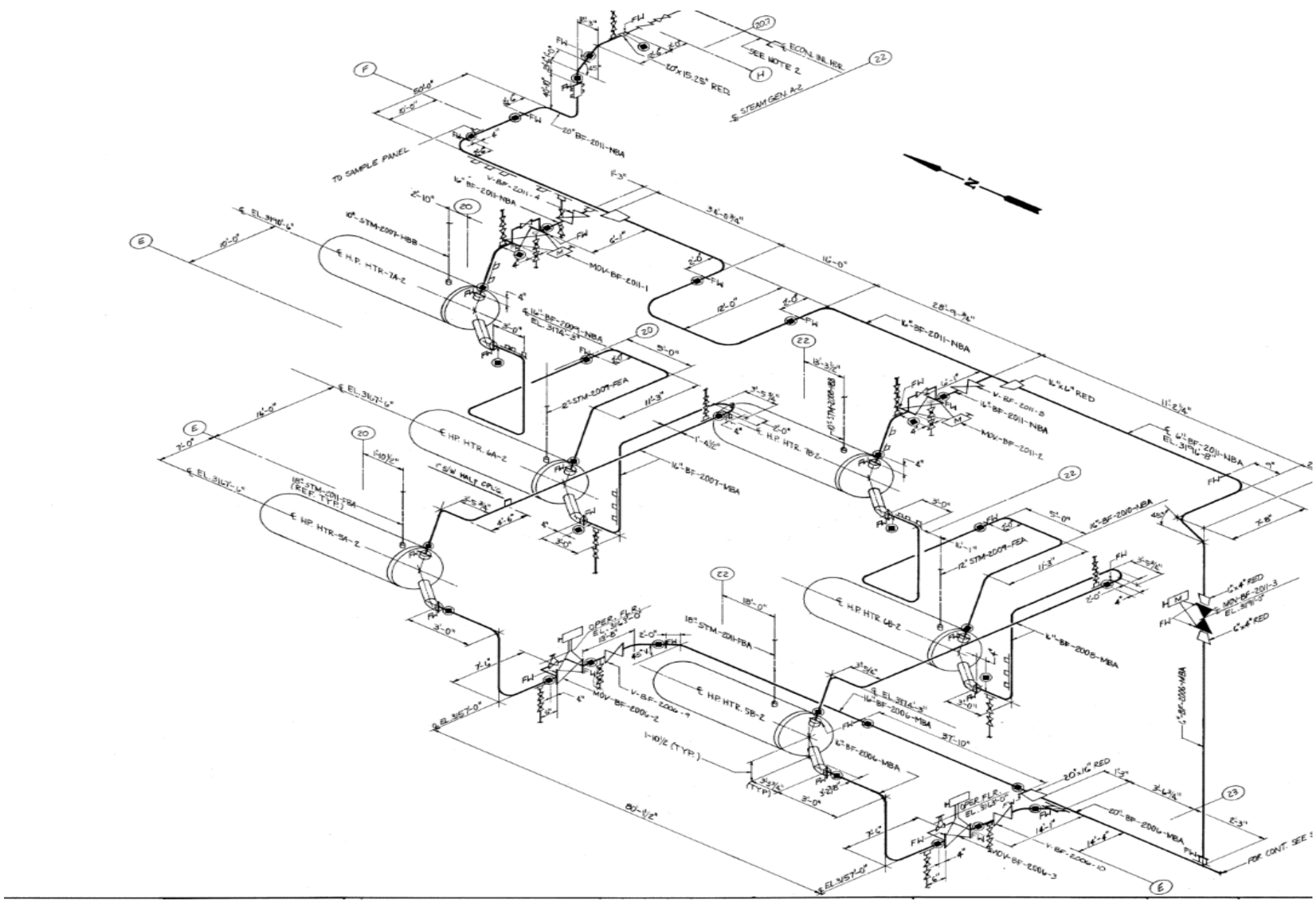
Identifying Valves to Monitor

1. **Identify the key "high to low energy" leakage paths at your plant.**
    1. Review feedwater heater isolation, including e-drains, bypass, startup vents and vent bypass
    2. Check steam traps (focus on high energy locations) for proper operation, and assure bypasses are closed.
    3. Steam turbine bypass valves, reheat drains, other high energy valves

Identifying Valves - Governor Valve Seat Drain

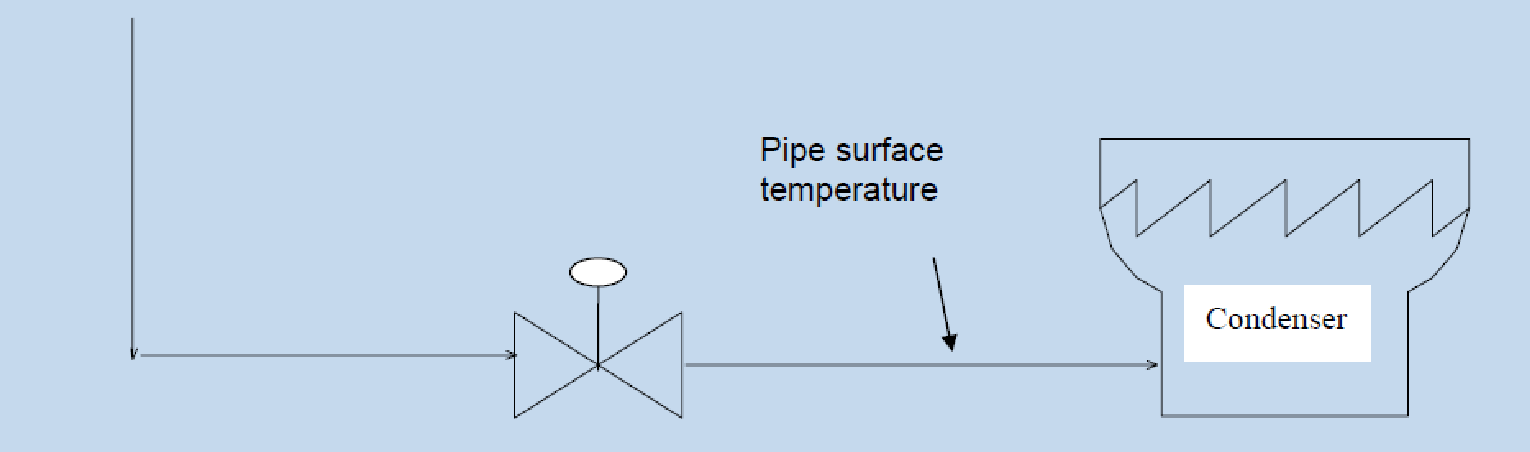


Identifying Valves - Isometrics



Walkdown and Measurement Locations

1. **Measure temperature upstream of valves.**
2. **Measure temperature downstream of valves.**
3. **May require cutting holes in insulation.**



Is a Valve Leaking?

Measure the temperature immediately upstream of the valve and downstream of the valve:

- **If both the upstream and the downstream temperatures are near the ambient temperature, the valve is not leaking**
- **If the upstream temperature is significantly above the ambient temperature but the downstream temperature is near the ambient, this valve has a small leak**
- **If both the upstream and downstream temperatures are significantly above the ambient temperature, this valve has a significant leak**

Prioritizing Valves?

- **Prioritizing potentially leaking valves is a function:**
  - Energy level of liquid or vapor upstream of the valve
  - Thermodynamic impact on the plant cycle
  - Extent of the valve leakage
- **Ranking valves is important because large valves are expensive to repair, so make sure the benefit is there.**
- **Realize the size of the leakage today will not be the size of the leakage tomorrow and that leaking valve repair is almost always cost effective.**

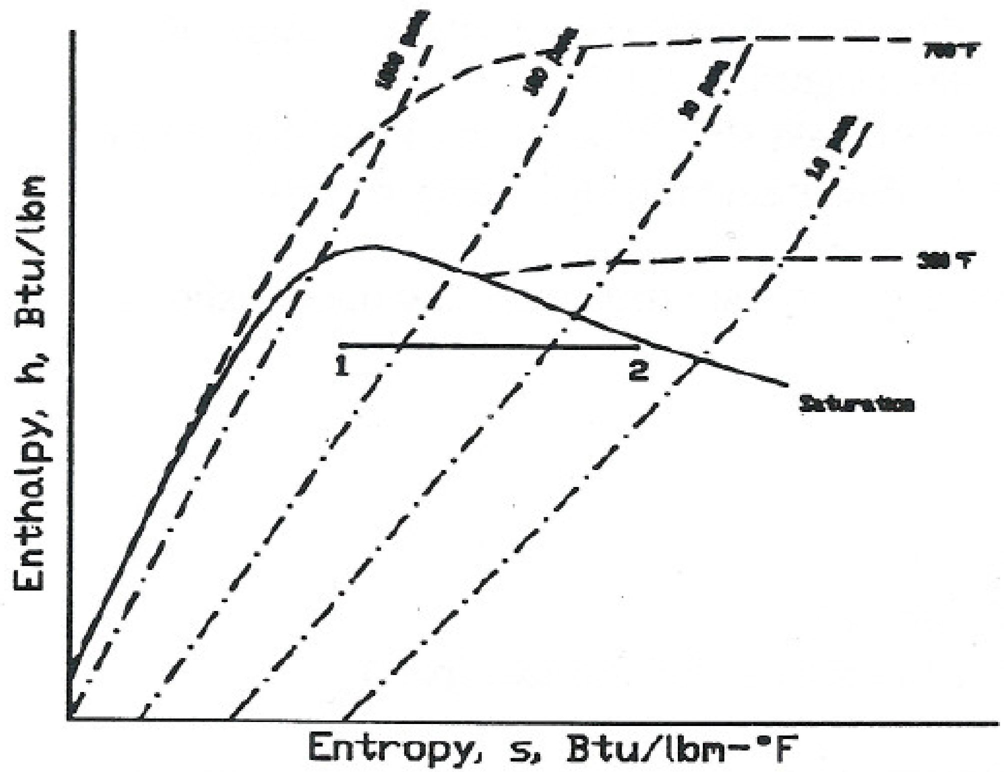
Determining Leakage

- **In general, the leakage estimation is obtained by:**
  - Determining a nominal downstream temperature for non-leaking valves
  - Establishing a downstream threshold temperature limit for identifying leaking valve
    - What temperature is indicative of a leak?
    - Using a threshold temperature limit helps avoid false positives
  - Calculation of the leakage flow and losses
    - Infer pressure inside pipe from downstream temperature measurement
    - Calculate flow of leaking fluid (high energy, high value)
    - Convert flow to heat rate and/or generation loss and cost

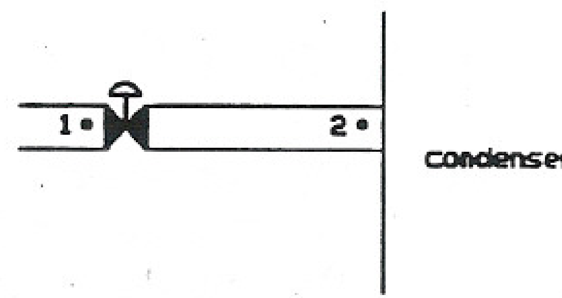
PMAX Cycle Isolation Calculations - Methods Used

- **Grashofs Method**
  - For conditions where the leakage is expected to be saturated steam, Grashofs equation can be used as an estimate of leakage flow. It is commonly used in nuclear power plants, deaerators, and steam drums. It has also been used to estimate superheated steam and subcooled liquid conditions. However, for superheated steam conditions the leakage is usually over estimated by this method.
- **ASME Figure 14 Method**
  - A method of estimating valve leakage assuming choking conditions exist. A general rule of thumb to determine choked flow conditions is if the pressure drop exceeds 2X.

PMAX Cycle Isolation Calculations – Grashofs Method



FV HTR EMRG VALVE LEAKAGE



$$Q_g = 59.4AP^{.97}$$

Where:

- Q_g = mass flow rate (lbm/hr)
- A = cross sectional area of pipe (in^2)
- P = saturated pressure downstream of valve (psia)
  - The pressure is determined from the saturated pressure using the measured temperature

PMAX Cycle Isolation Calculations – Grashofs Method

Step 1: Calculate Flow Area – ID
Step 2: Find saturation pressure downstream of valve (P_d)
Step 3: Find the saturation pressure (P_r) of the ambient temperature
Step 4: Use Grashof's equation to find the flow from the ambient temperature (Q_r)
Step 5: Use Grashof's equation to find the flow uncorrected for moisture (Q_g)
Step 6: Find the enthalpy upstream of the valve (h_T)
Step 7: Find the enthalpies of gas downstream (h_g) and fluid downstream (h_f)
Step 8: Calculate the moisture flow (Q_f)

$$Q_f = Q_g \times \frac{h_g - h_f}{h_T - h_f} - Q_g$$

Step 9: Calculate the total flow (Q_T)

$$Q_T = Q_f + Q_g$$

Step 10: Find a moisture correction factor off the graph (Figure 2-6)

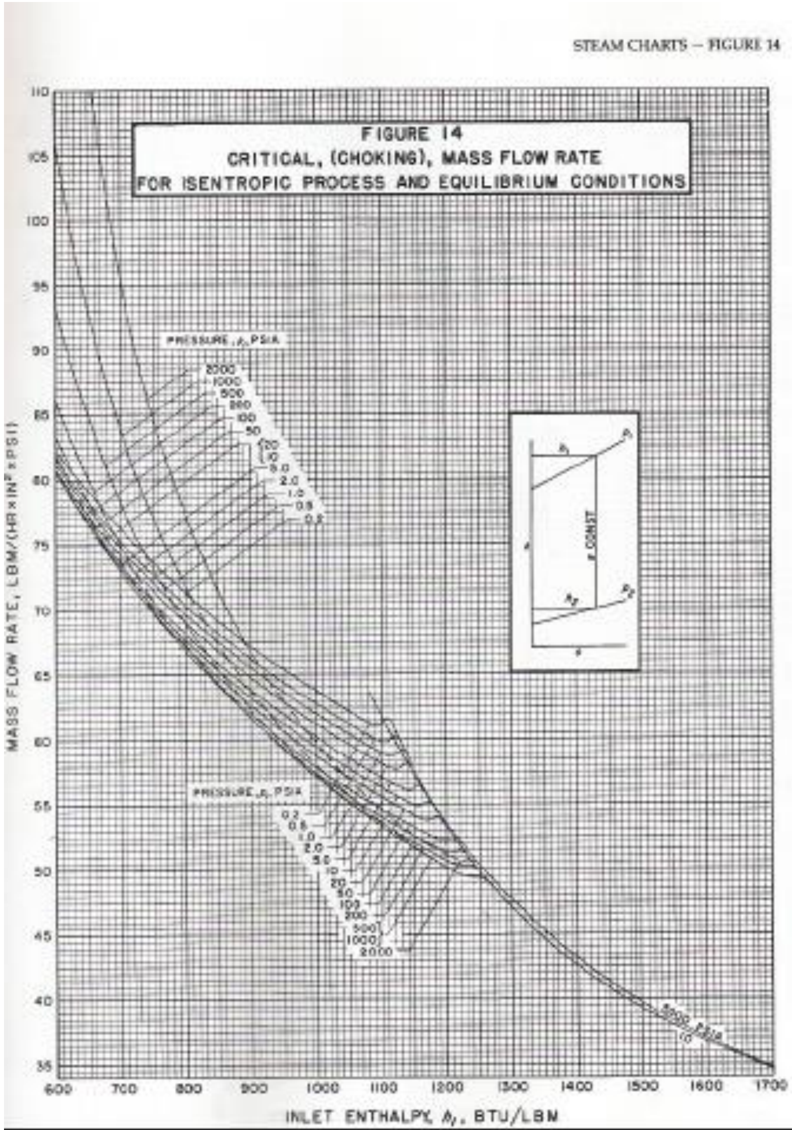
$$Moisture\,\% = \frac{Q_f}{Q_T} \rightarrow \text{From graph } C_f$$

Step 11: Determine corrected flow (Q_C)

$$Q_C = \mathrm{Cf} \times Q_T$$

Step 12: Find the estimated lost generation and heat rate impact

PMAX Cycle Isolation Calculations – ASME Figure 14 Method



ASME Figure 14 provides the mass flow rate per in^2 of flow area per psi of pressure, m', as a function of up-stream enthalpy and pressure.

PMAX Cycle Isolation Calculations – ASME Figure 14 Method

Step 1: Calculate Flow Area – ID
Step 2: Find saturation pressure downstream of valve (P_d)
Step 3: Find the enthalpy of the gas downstream of the valve (h_g)
Step 4: Use ASME Figure 14 to find the critical mass flow rate downstream of the valve

Using h_g and P_d on ASME Figure 14 → W_P

Step 5: Determine the uncorrected flow at the saturated conditions downstream (Q_g).

$$Q_g = W_P \times A \times P_d$$

Step 6: Find the enthalpy upstream of the valve (h_T)
Step 7: Find the enthalpies of gas downstream (h_g) and fluid downstream (h_f)
Step 8: Calculate the moisture flow (Q_f)

$$Q_f = Q_g \times \frac{h_g - h_f}{h_T - h_f} - Q_g$$

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$$Moisture\,\% = \frac{Q_f}{Q_T}$$ → From graph C_f

Step 11: Determine corrected flow (Q_C)

$$Q_C = \mathrm{Cf} \times Q_T$$

Step 12: Find the estimated lost generation and heat rate impact

PMAX Cycle Isolation Calculations – Valve Specific Constants

- Pipe inside diameter (in)
- Correction for equivalent hydraulic length (optional) – pressure correction for the pressure inferred from the downstream temperature of the valves (psia)
- Loss factor - obtained from PEPSE to convert estimated leakage flow to generation and/or heat rate impact.

PMAX Cycle Isolation Calculations – Plant Measurements

- **Gross generation (MWe)**
- **Gross turbine cycle heat rate (obtained from existing PMAX calculation or calculated based on measured temperatures, pressures, flows and generation) (Btu/kWh)**
- **Pressure (psia) and temperature (°F) upstream of valves (to obtain enthalpy)**
  – In some cases, the conditions are saturated steam and/or liquid to obtain enthalpy (SG outlet, boiler drum, deaerator, etc.)
  – In most cases, these already exist in PMAX system models
- **Pipe metal temperature downstream of the valves (contact metal thermocouple) – BWR plants. Alternatively, this is obtained from manual entry (°F)**

PMAX Cycle Isolation Calculations – Manual Inputs

- **Current Tailpipe Temperature (°F)**
  - pipe metal temperature downstream of each valve
- **Surrounding Temperature (°F)**
  - Ambient room temperature in the vicinity of the downstream pipe metal temperature downstream of each valve
- **Threshold Temperature (°F)**
  - Threshold temperature check to activate the estimated leakage calculation of each valve
- **User Correction (0-1)**
  - User correction factor applied to the final estimated leakage flow rate (-)

PMAX Cycle Isolation Calculations – Results

- **Leakage Flow (lb/hr)**
  - Estimated valve leakage flow rate with all corrections applied
- **ΔMW (MWe)**
  - Estimated valve leakage generation impact
- **ΔHR (Btu/kWh)**
  - Estimated valve leakage heat rate impact
- **Valve Total – Total Losses**
  - Total generation impact (MWe) and heat rate (Btu/kWh) from all leaking valves

PMAX Cycle Isolation Display

Valve Total	ΔMW (MWe)	ΔHR (Btu/kWh)
Total Losses	-11.2	611.5

Controllable Losses

Help | Help | Help | Help

Definitions

Valve	Current Tailpipe Temp (°F)	Surrounding Temp (°F)	Threshold Temp (°F)	User Correction (0-1)	Leakage Flow (lb/hr)	ΔMW (MWe)	ΔHR (Btu/kWh)
MS Safety	279.0J	100.0J	150.0J	1.0J	54814.2	-8.3	449.8
CRH Safety	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
CRH Safety	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
CRH Safety	205.0J	100.0J	150.0J	1.0J	27063.3	-3.0	161.7
HRH Safety	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
LP HTR 3 ES Safety > ATM	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
MS ELECTROMATIC RELIEF > ATM	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
BOILER FILL VALVE	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
LP HTR 1 FW BYPASS	92.0J	100.0J	120.0J	1.0J	0.0	0.0	0.0
DA BELLY DRAIN > BDTK	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
DA BELLY DRAIN > BDTK	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0
SUPERHEAT ATTEMP A SHUTOFF	120.0J	100.0J	150.0J	1.0J	0.0	0.0	0.0

Summary

- Cycle isolation monitoring is frequently overlooked in power plants.
- It is one of the largest losses at many plants and is mostly a controllable loss.
- Losses in excess of 400 Btu/kWh have been documented.
- PMAX is an excellent platform to estimate leaking valve flow and provide a generation and heat rate impact.
- Interactive PMAX displays are easily accessed by operators and engineers to estimate the impact of high energy valve leakages.

