ME444 ENGINEERING PIPING SYSTEM DESIGN

CHAPTER 12: STEAM PIPING SYSTEM (2)

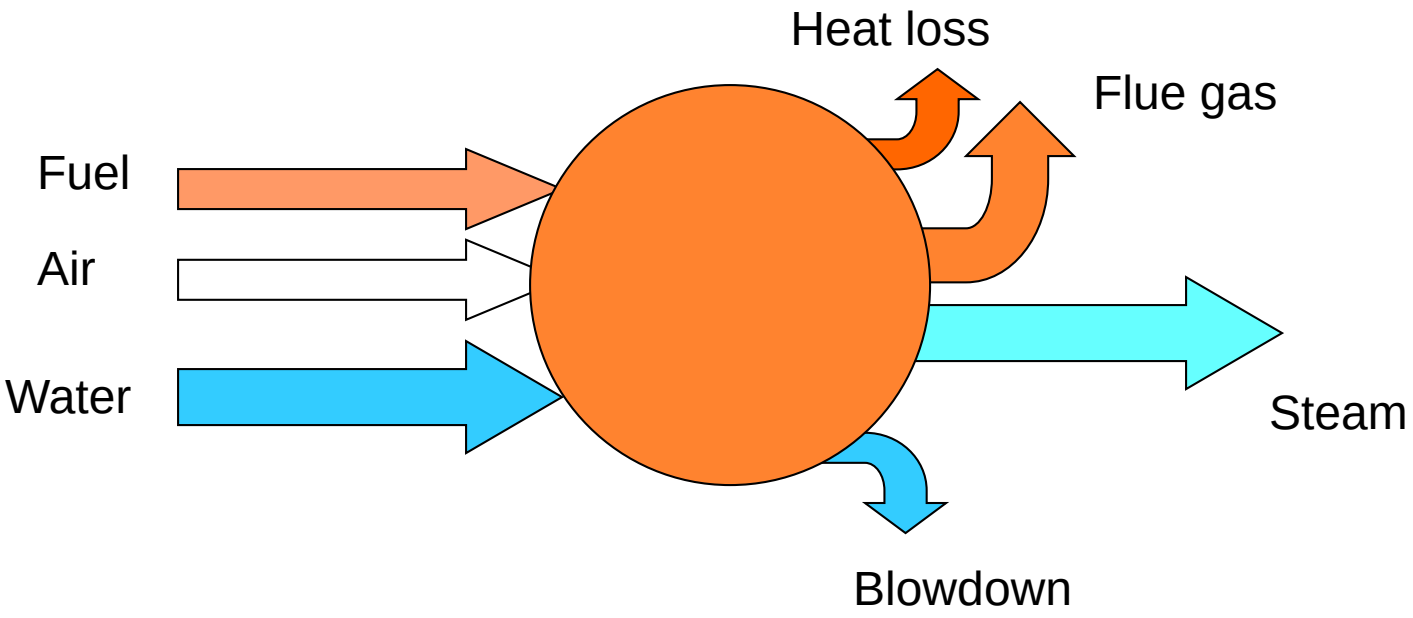
CONTENTS

1. COST OF STEAM

1 kg/h of saturated steam at ambient pressure

= 2257 kJ/hr

= 627 watt



CALCULATING COST OF STEAM

Example

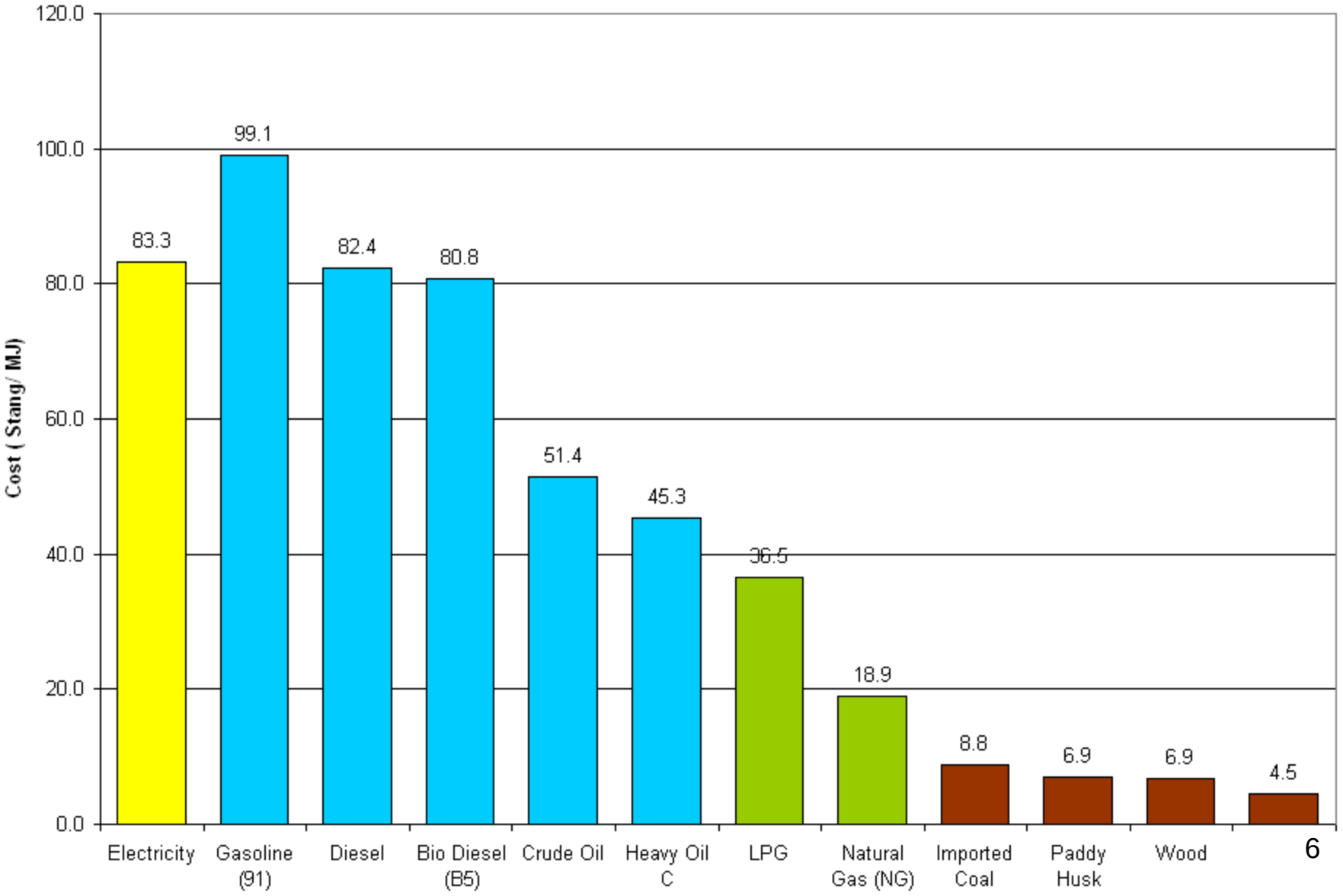
Calculate the cost of generating 1 kg of steam at 8 barg from 30C feed water using heavy oil C. Boiler efficiency is 80%

Feed water temp 30 C: enthalpy,	h1 = 4.18x30 = 125.4 kJ/kg
Saturated steam at 8 bars: enthalpy	h2 = 2779.66 kJ/kg
Heat input (per kg)	h2-h1 = 2654.26 kJ/kg
Heating value of heavy oil C	= 39.77 MJ/litre
Boiler efficiency	= 80%
Oil require = 2654.26 / 39.77/1000 / 80%	= 0.0834 litre/ kg of steam
Cost of oil (approximated)	= 18 baht/litre
Cost of steam = 18*0.0834	= 1.5 baht / kg of steam

COST OF STEAM

Fuel	unit	LHV MJ/unit	Cost (baht/unit)	Efficiency	Cost of steam (baht/kg)
Natural Gas	kg	45.00	8.5	85%	0.59
Petroleum Gas	kg	49.29	18	85%	1.14
Diesel	litre	36.42	30	80%	2.73
Heavy Oil	litre	39.77	18	80%	1.50
Electricity	kWh	3.60	3	90%	2.46
Lignite (Mae moh)	kg	10.47	0.5	70%	0.18
Wood	kg	15.99	1	60%	0.28
Paddy husk	kg	14.40	1	60%	0.31

COST OF ENERGY

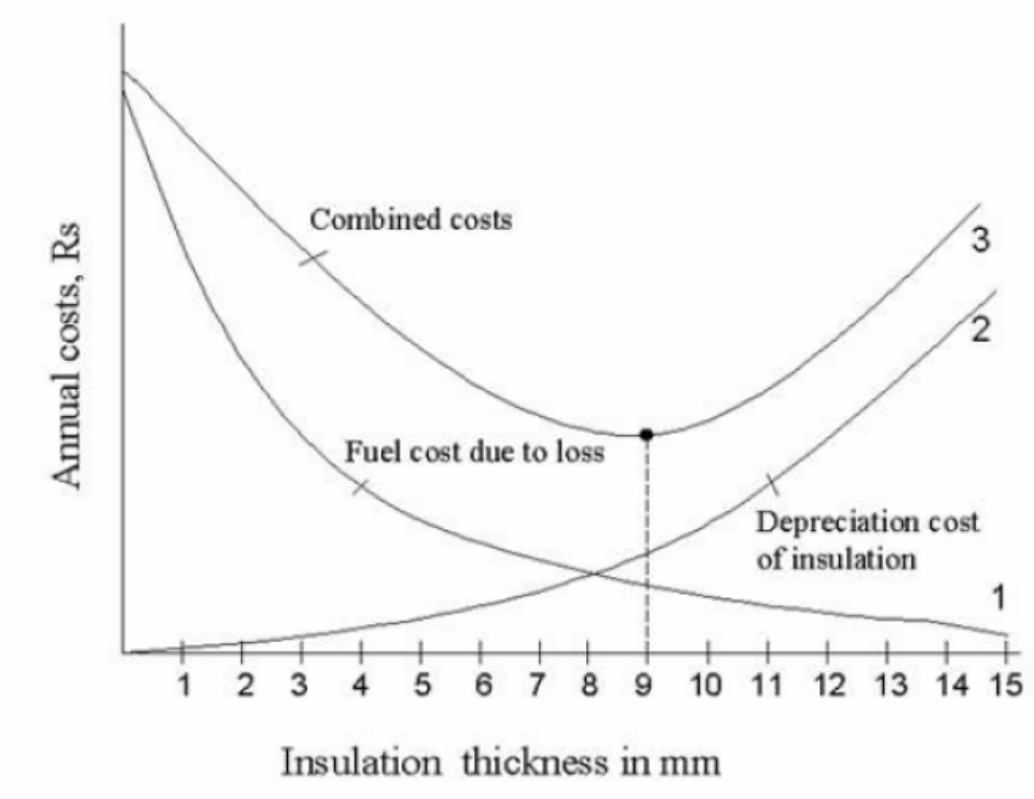


2. HEAT LOSS AND INSULATION

Insulation is required to

- Reduce heat loss (w/o insulation loss ≈ 2000 watt/m^2)
- Prevent injury (maintain surface temp < 50C)

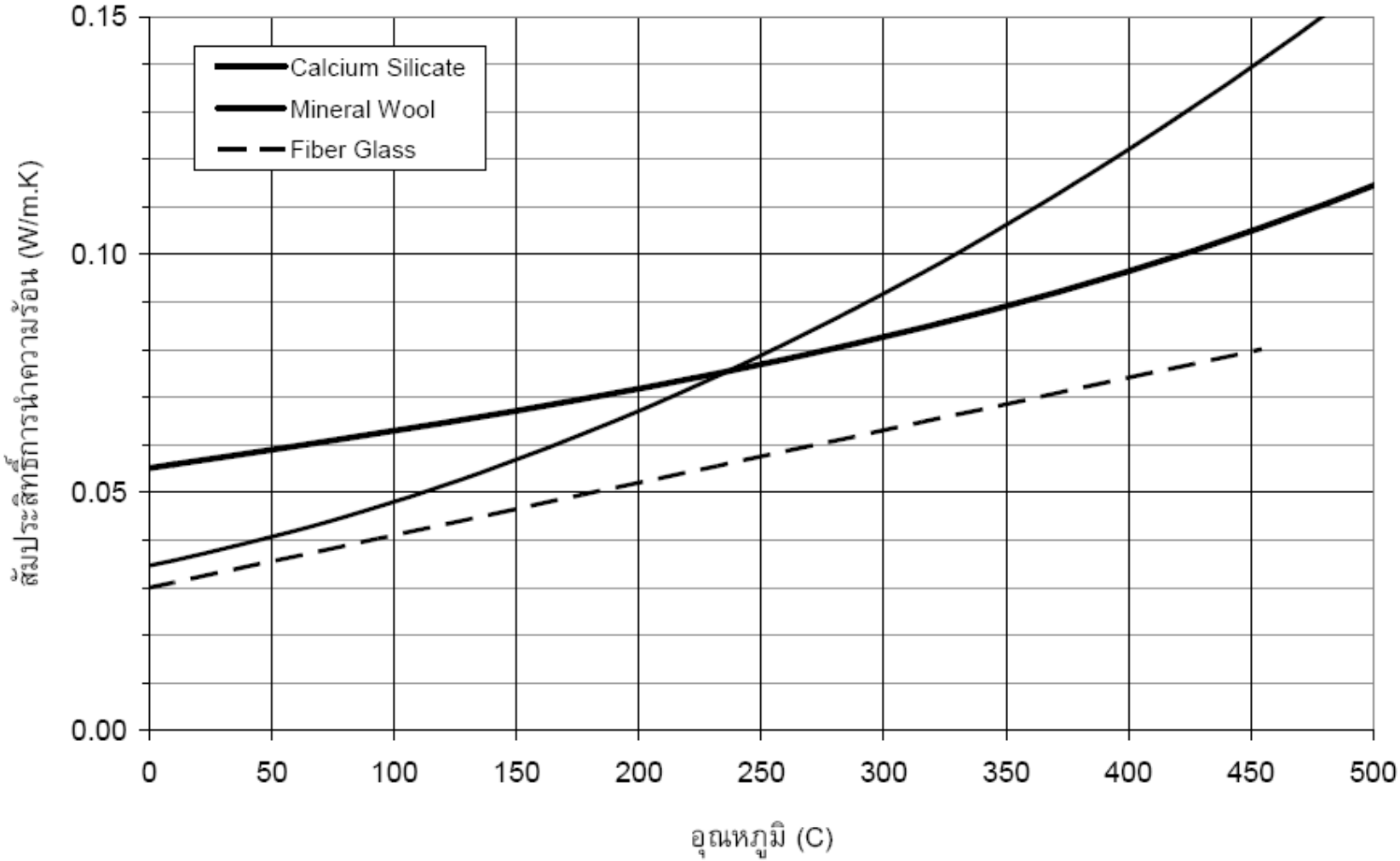
OPTIMUM INSULATION THICKNESS



PROPERTIES OF INSULATIONS

ฉนวน	อุณหภูมิสูงสุด(°C)	ค่า k ที่ 150 °C	สมการหาค่า k
แคลเซียมซิลิเคต	550	0.067	1.3070E-07T^2 + 5.1223E-05T + 5.5839E-02
ใยแร่	650	0.057	2.8045E-07T^2 + 1.0632E-04T + 3.4652E-02
ใยแก้ว	450	0.046	1.1025E-04T + 2.9990E-02

THERMAL CONDUCTIVITY



RECOMMENDED THICKNESS

ขนาดท่อ DN	ช่วงอุณหภูมิของของไหล (°C)			
	50 - 90 น้ำร้อน	90 - 120 ไอน้ำความดันต่ำ	120 - 150 ไอน้ำความดันปานกลาง	150 - 230 ไอน้ำความดันสูง
15-25	25	40	50	65
32-50	25	40	65	65
65-100	40	50	65	80
125-150	40	50	80	90
200 ขึ้นไป	40	50	80	90

CALCULATION OF HEAT LOSS

KNOW T_F AND T_A

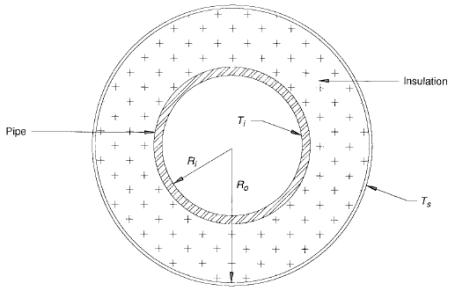
KNOW PIPE SIZE, PIPE THICKNESS AND INSULATION THICKNESS

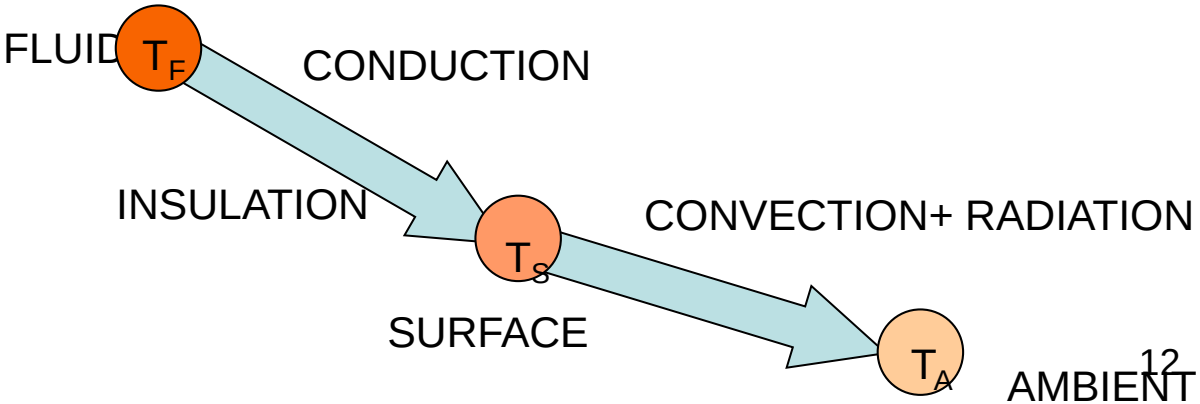
SET

$$Q_{COND} = Q_{CONV+RAD}$$

$$\frac{T_F - T_S}{\ln(r_2/r_1)/2\pi k_1 L + \ln(r_3/r_2)/2\pi k_2 L} = \bar{h}A(T_S - T_A) + \varepsilon\sigma\left(T_S^4 - T_A^4\right)$$

SOLVE FOR T_s





HEAT LOSS FROM STEAM PIPE

ขนาดท่อไอน้ำ (DN)	อุณหภูมิไอน้ำ (deg C)	ความร้อนสูญเสียที่อุณหภูมิสิ่งแวดล้อม 30 °C ลมสงบ (watt/m)* ความหนาของฉนวนแคลเซียมซิลิเคต (mm)**						
		0 (ไม่หุ้ม)	25	38	50	63	80	100
80	75	157	28	22	19	17	15	13
	100	275	45	35	30	26	23	21
	125	410	62	49	42	36	32	28
	150	565	81	63	54	47	41	37
	175	741	100	78	66	58	51	45
	200	938	120	93	79	69	61	54
100	75	196	34	26	22	19	17	15
	100	342	54	42	36	31	27	24
	125	512	75	58	49	43	37	33
	150	706	98	75	64	55	48	42
	175	926	121	93	79	68	59	52
	200	1,174	145	112	94	82	71	62
125	75	237	40	31	26	23	20	17
	100	413	64	49	41	36	31	27
	125	617	89	68	57	50	43	38
	150	852	116	88	74	64	55	48
	175	1,118	143	109	92	79	68	60
	200	1,419	172	131	110	94	81	71

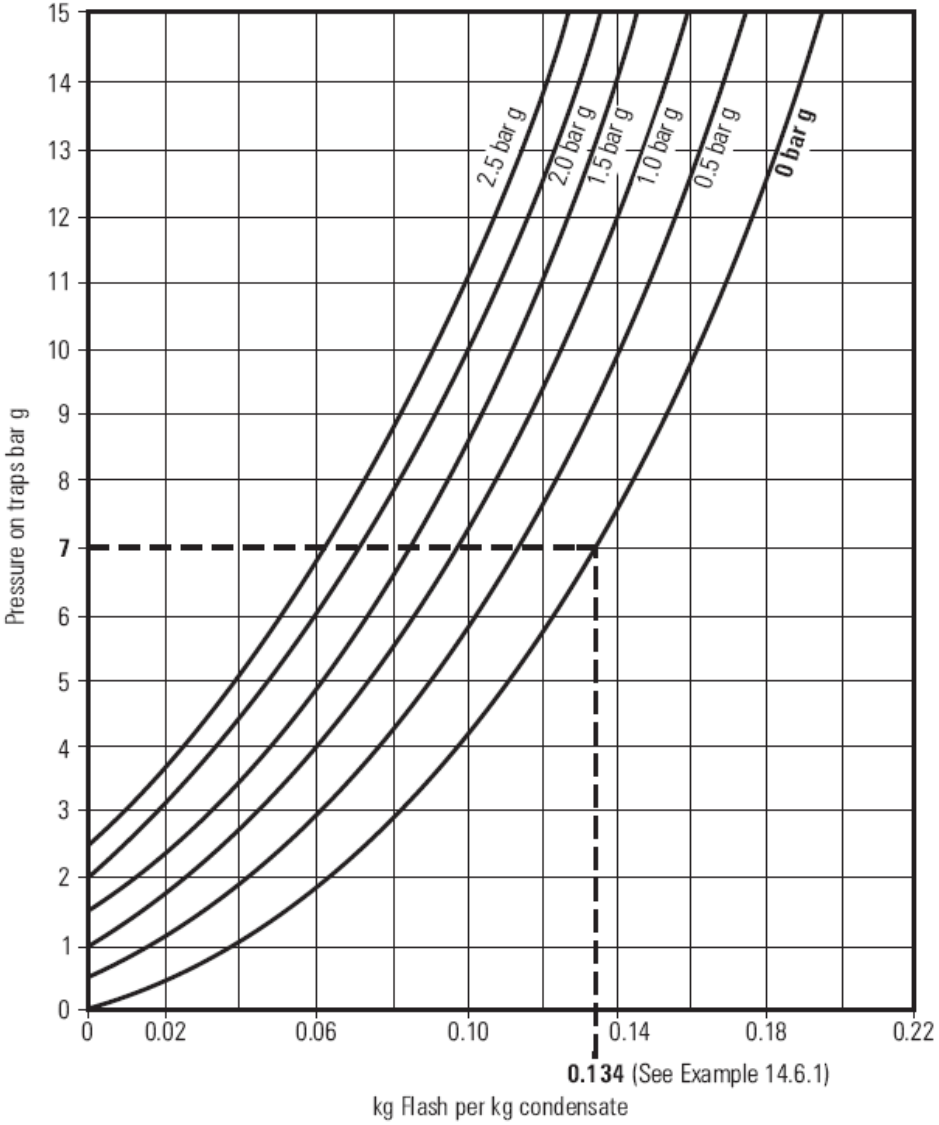
[TABLE 11.4]

3. DESIGN OF CONDENSATE PIPE

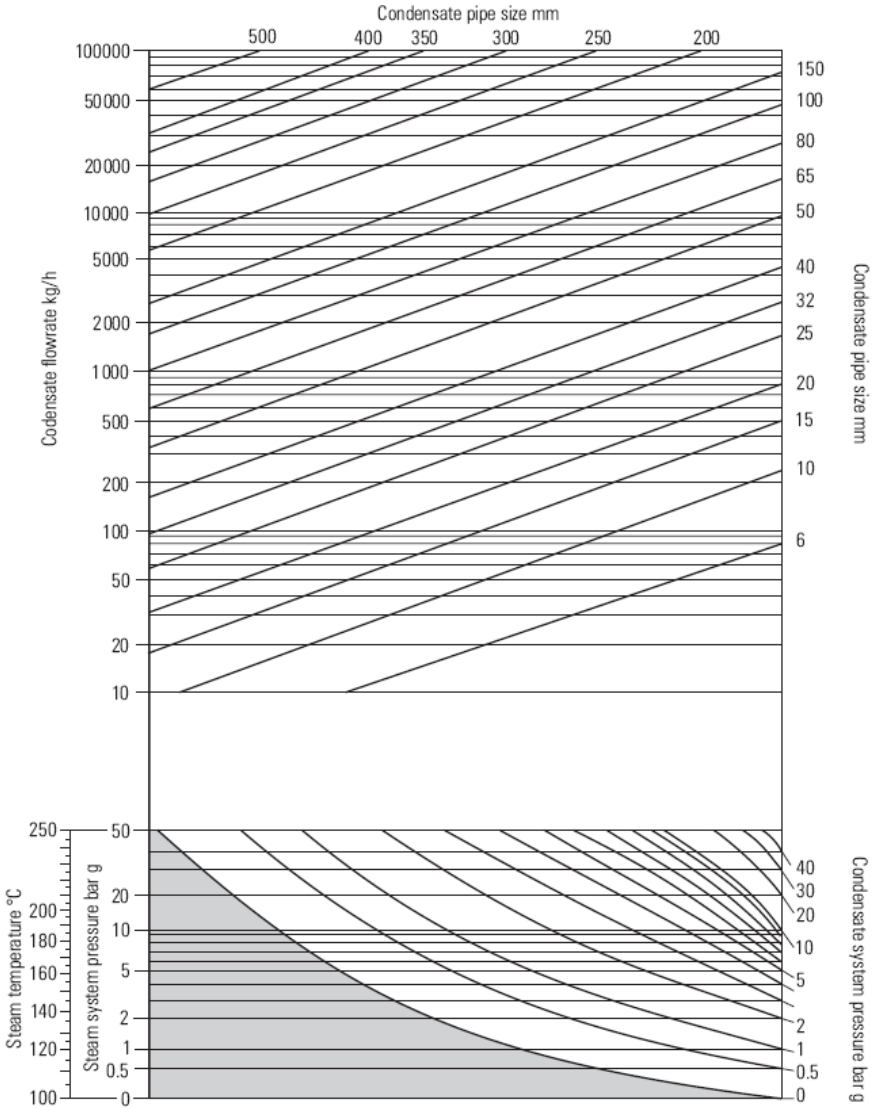
$$\dot{m} = 3600 \frac{Q_{loss}}{h_{fg}}$$

- Condensate can be driven by steam pressure
- Velocity < 1 m/s
- Pressure drop < 1 m/100m
- Flash steam may occur along the way

FLASH STEAM FROM CONDENSATE



CONDENSATE PIPE SIZING CHART



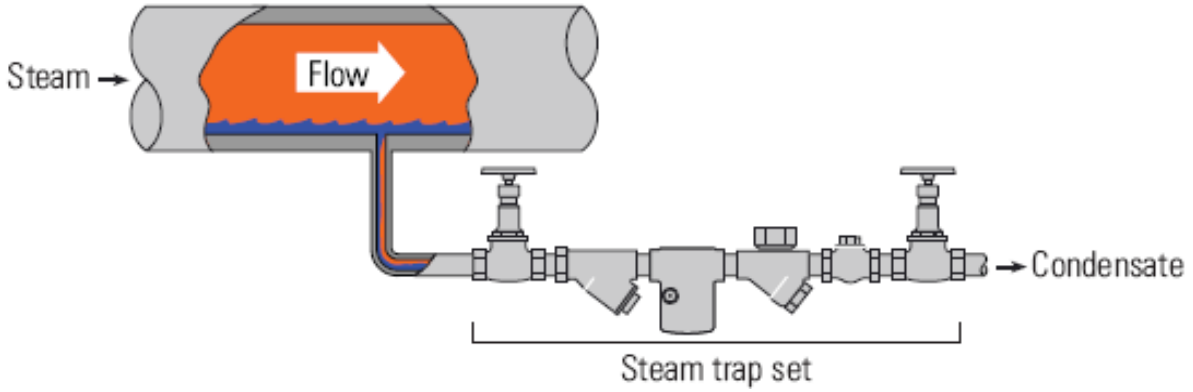
4. STEAM TRAPS

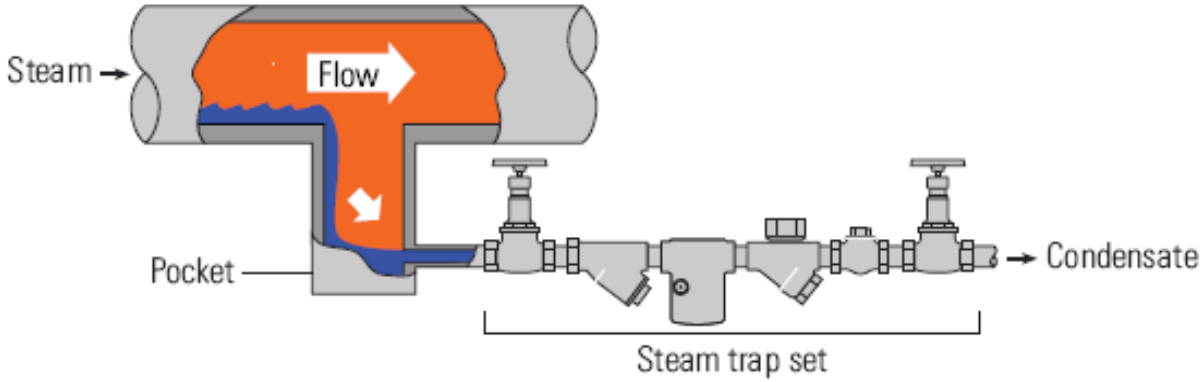
Ball float type | Thermodynamic type | Thermostatic type

TO REMOVE CONDENSATE AND AIR FROM STEAM SYSEM
INSTALL AT:

- STEAM HEADER
- MAIN LINE (EVERY 30 TO 50 m)
- BOTTOM OF VERTICAL PIPE
- DROP PIPE BEFORE CONTROL VALVE OR PRV
- EQUIPMENT OUTLET

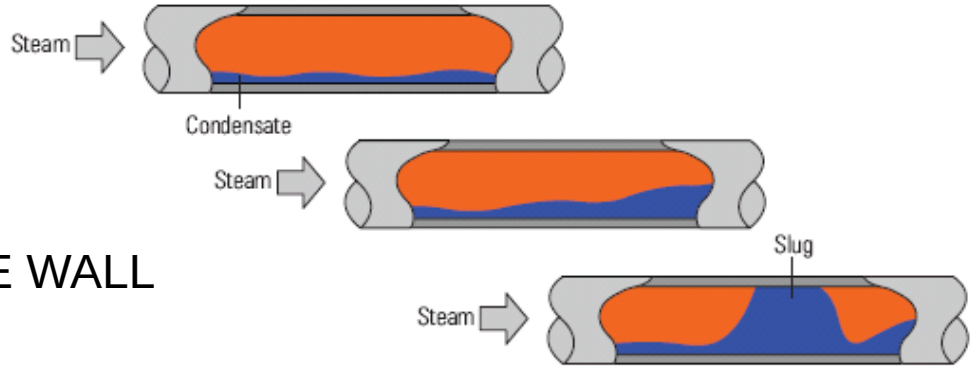
INSTALLATION

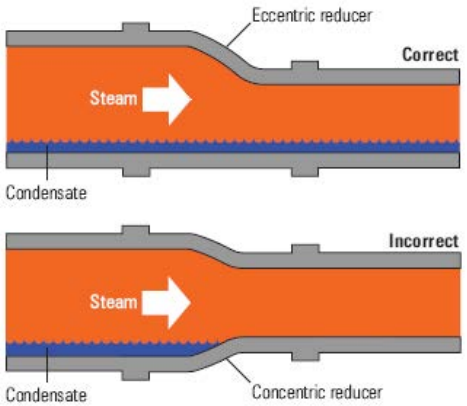


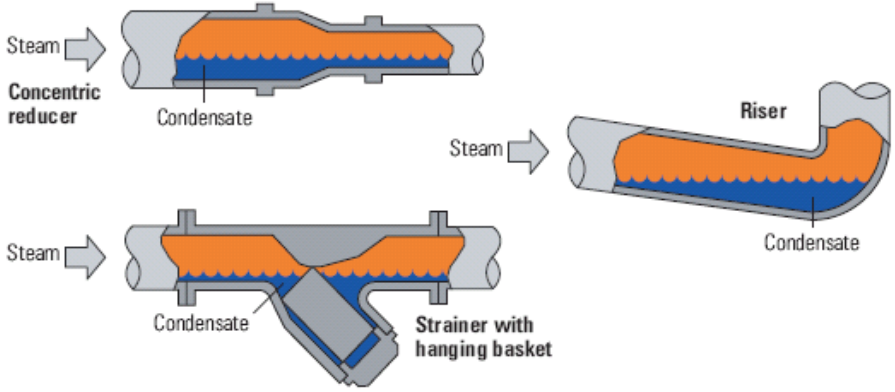


WATER HAMMER

OCCURS WHEN CONDENSATE
MOVES FAST AND HIT THE PIPE WALL

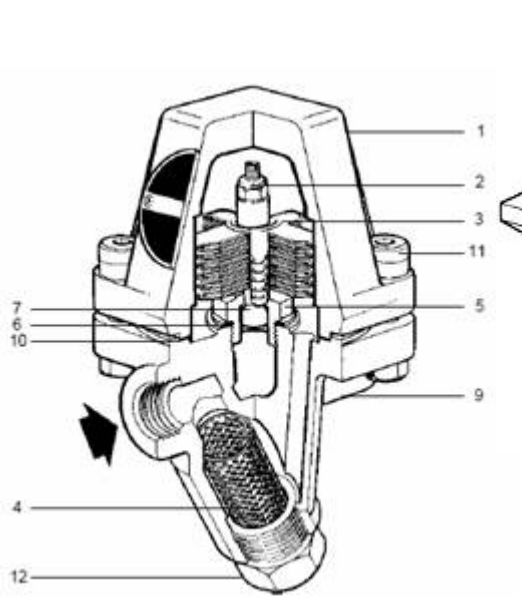


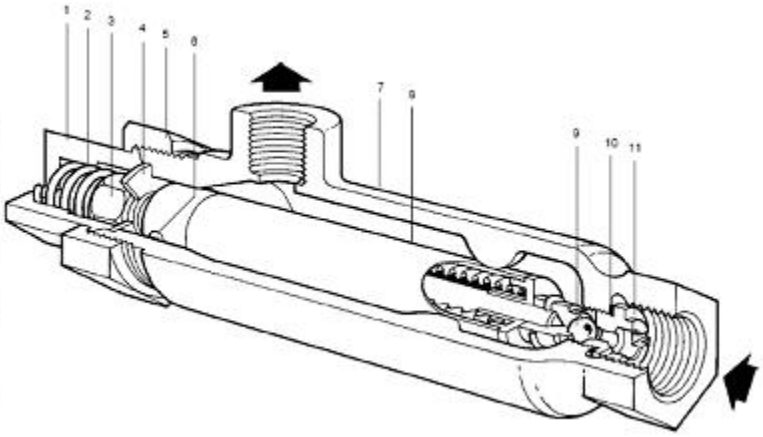


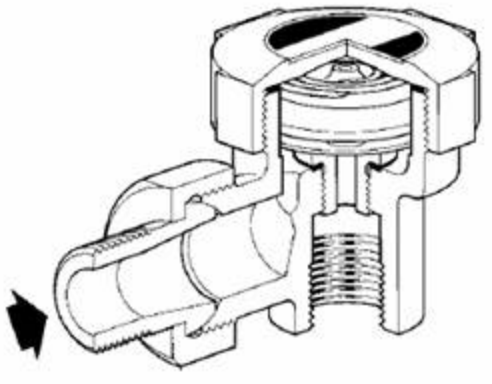


THERMOSTATIC STEAM TRAPS

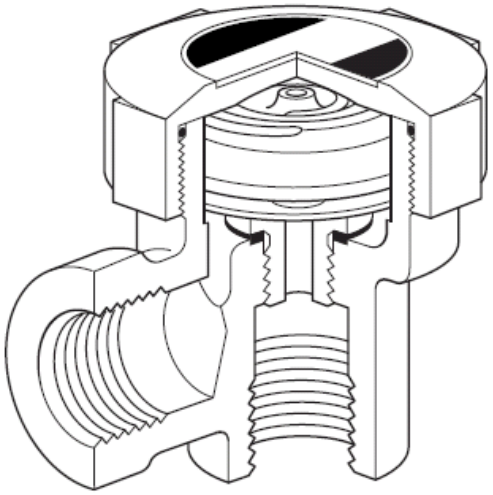
UTILIZE TEMPERATURE DIFFERENCE OF STEAM, CONDENSATE AND AIR

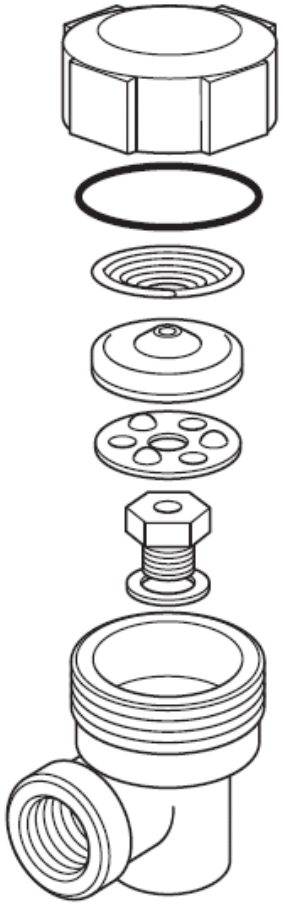


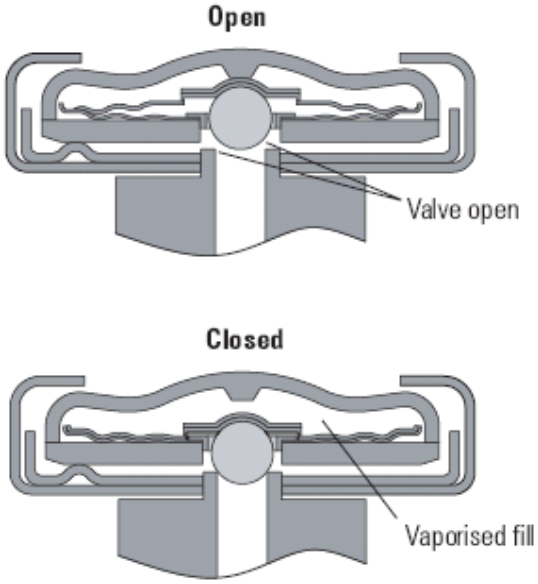




BALANCED PRESSURE STEAM TRAPS



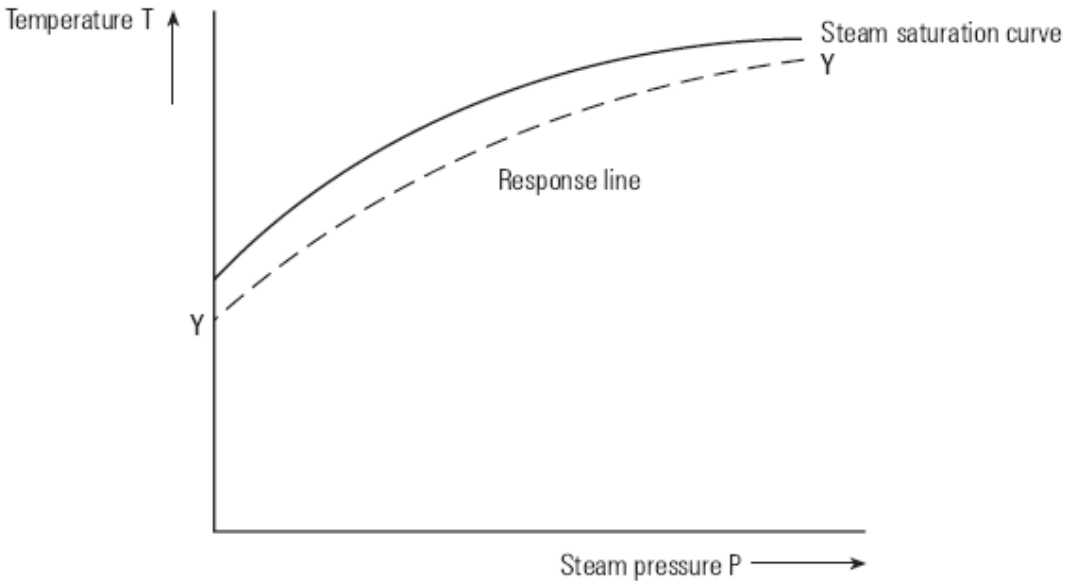




Capsule filled with liquid with lower boiling point

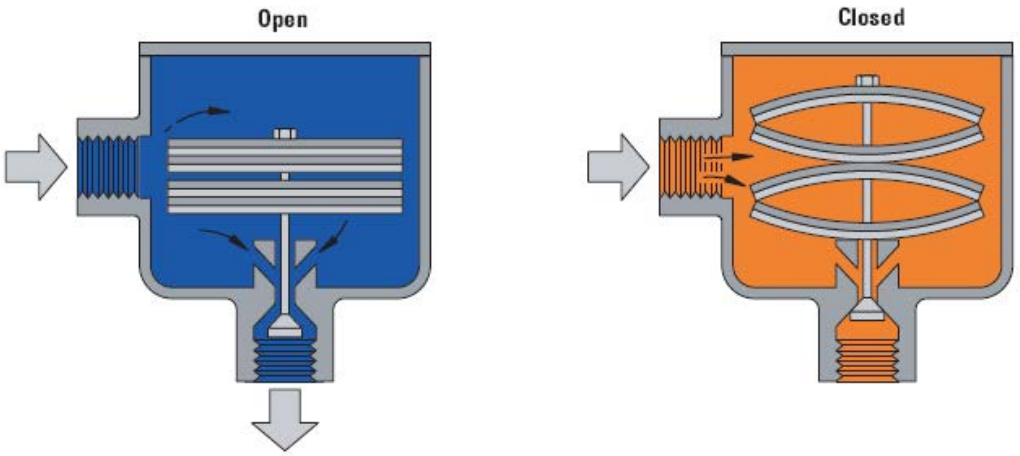
NOT SUITABLE FOR WATER HAMMER

RESPONSE OF BALANCED PRESSURE STEAM TRAPS



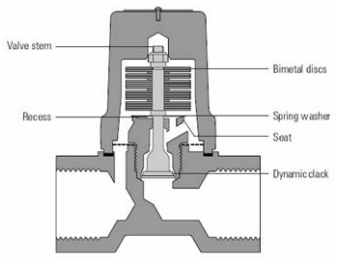
Do not open until condensate temperature drop below steam temperature

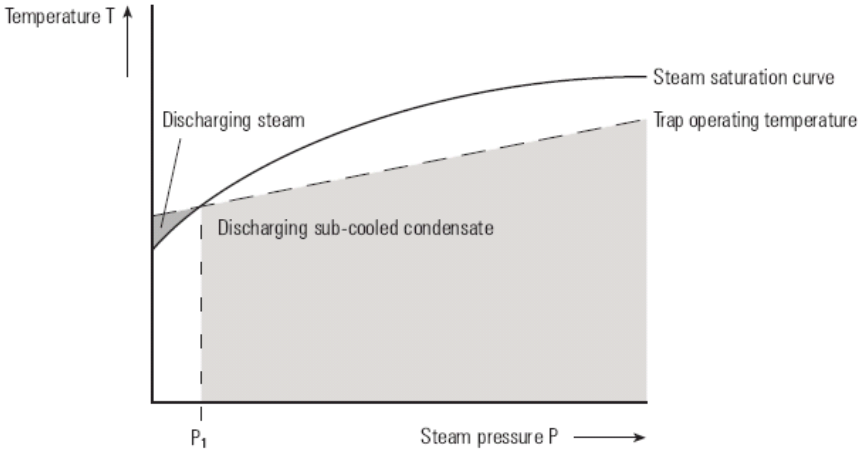
BIMETALLIC STEAM TRAPS



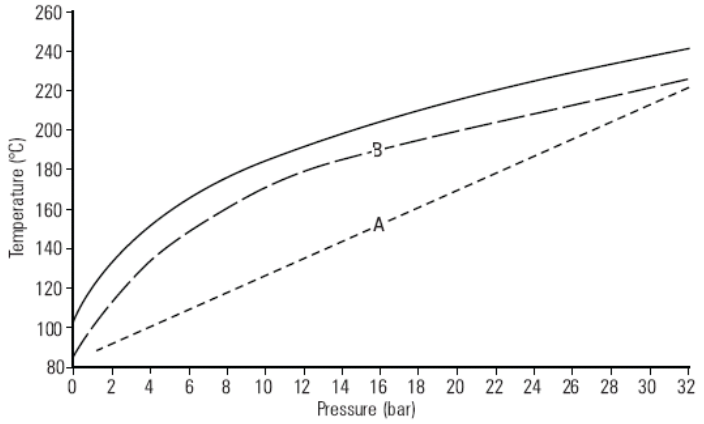
EMPLOY DIFFERENT THERMAL EXPANSION OF TWO METAL STRIPES

RESPONSE OF BIMETALLIC ELEMENT





SINGLE ELEMENT



MULTI ELEMENTS

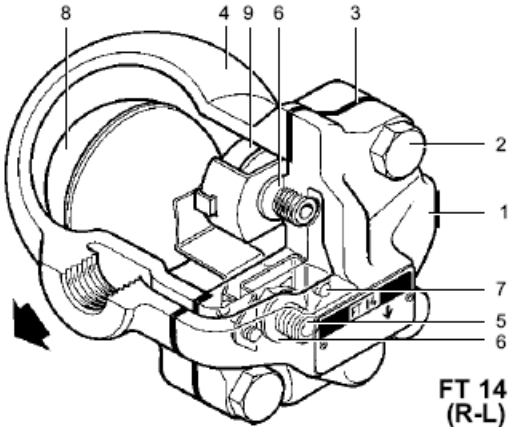
MECHANICAL STEAM TRAPS

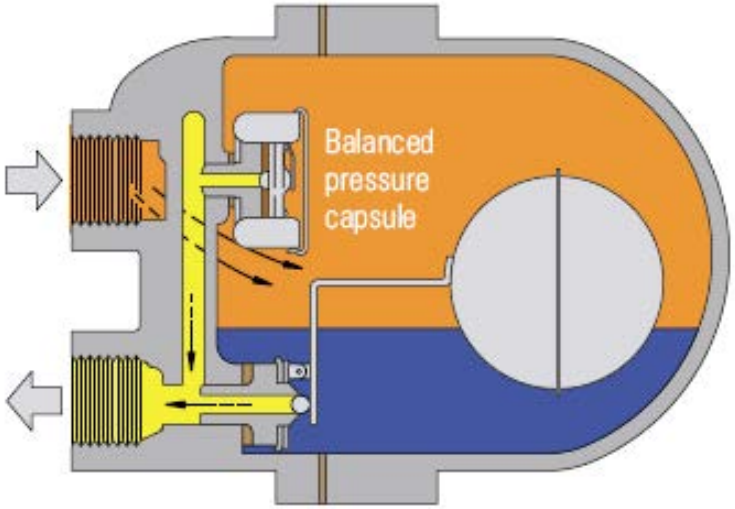
OPERATE ON DENSITY DIFFERENCE BETWEEN CONDENSATE AND STEAM

REQUIRE AIR VENT (BUILT IN OF SEPARATE INSTALLED)

MUST BE INSTALLED IN HORIZONTAL POSITION

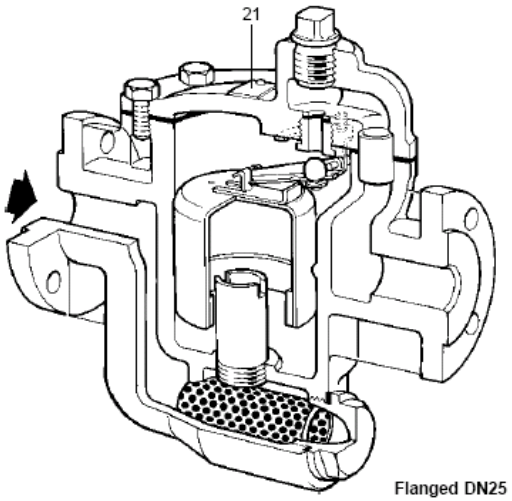
BALL FLOAT STEAM TRAPS

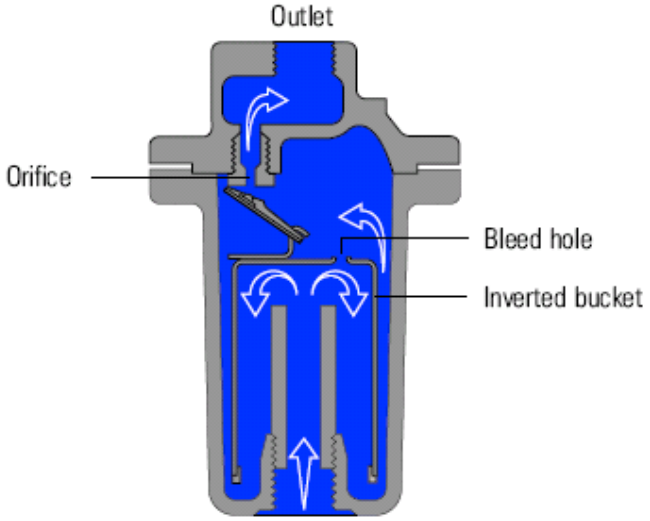


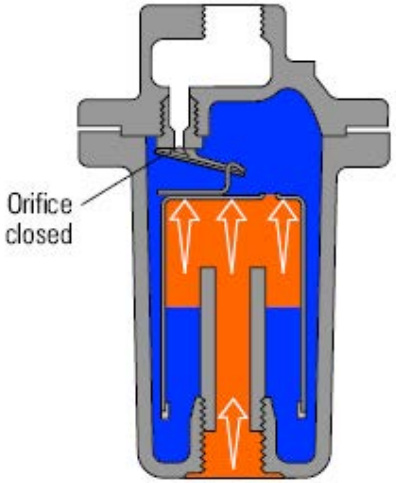


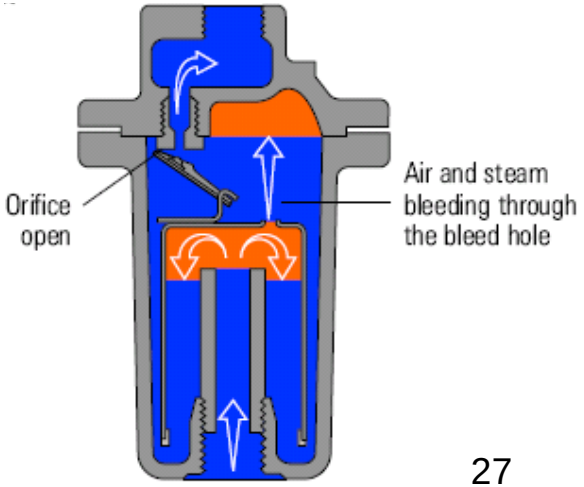
NOT SUITABLE FOR WATER HAMMER

INVERT BUCKET STEAM TRAPS

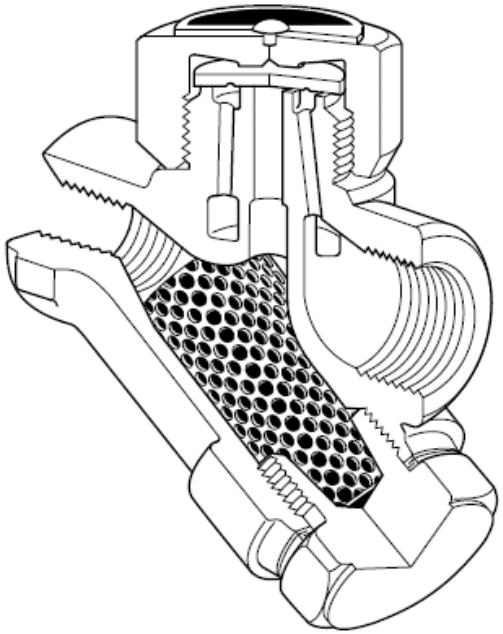








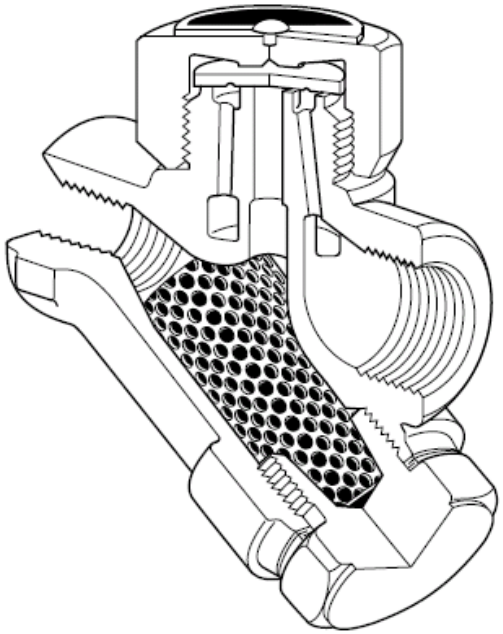
THERMODYNAMICS STEAM TRAPS

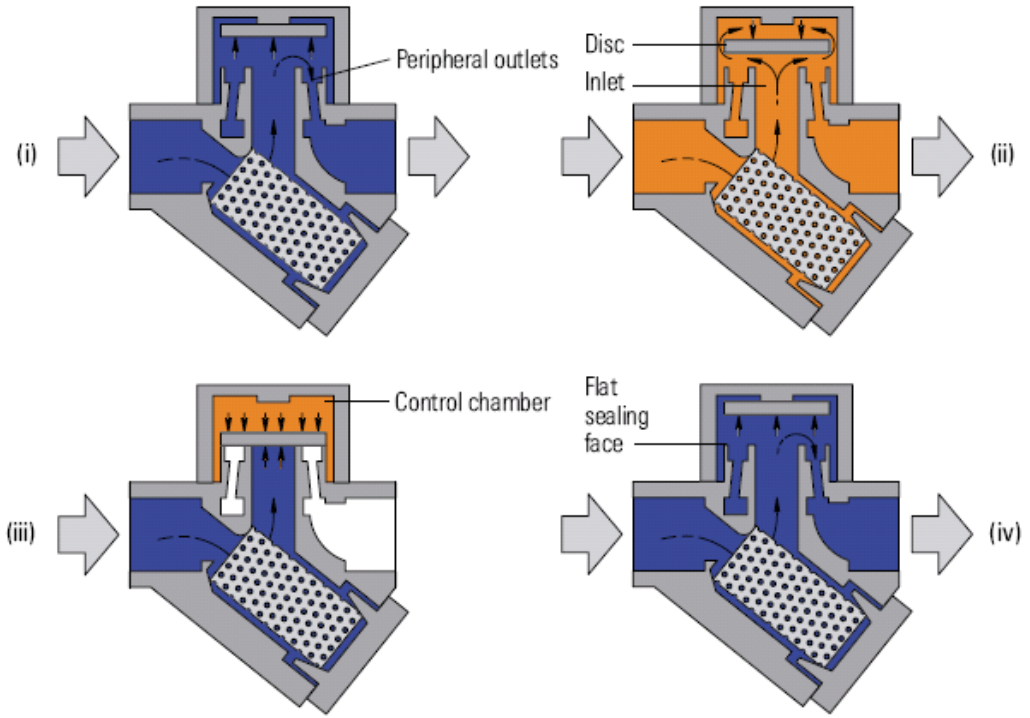


UTILIZE FORCE FROM AREA DIFFERENCE

LIMITED BACK PRESSURE

THERMODYNAMICS STEAM TRAPS



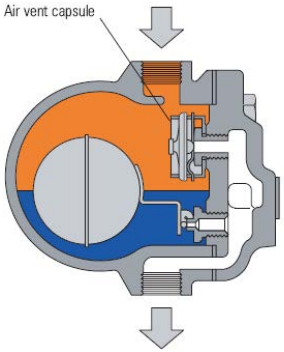


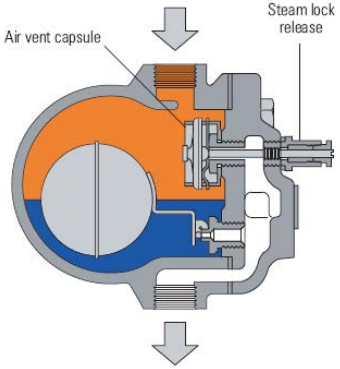
UTILIZE FORCE FROM AREA DIFFERENCE

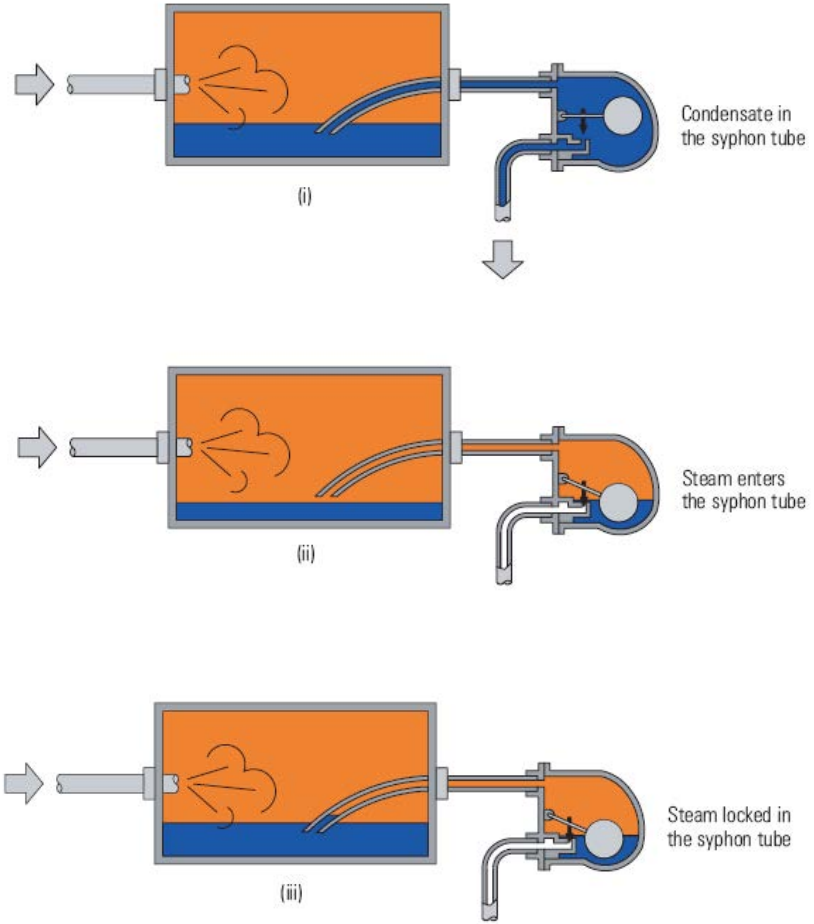
LIMITED BACK PRESSURE

STEAM LOCK

OCCUR IN A ROTATED MACHINE WHERE SYPHON TUBE IS USED.







SELECTING STEAM TRAPS

Steam trap:	FT range (float-thermostatic)	FT-C (float-thermostatic with steam release)	TD range (Thermodynamic)	BPT (Balanced pressure thermostatic)	SM (Bimetallic)	No.8 (Liquid expansion)	IB range (Inverted bucket)
Canteen equipment							
Boiling pans - tilting		B		A[2 5]			
Boiling pans - fixed	A	B	B[1]	B			
Boiling pans - pedestal	B			A[2 5]			
Steaming ovens				A[2 5]			
Hot plates	B			A[2 5]			
Oil transfer/storage							
Bulk oil storage tanks	A						B[1]
Line heaters	A						B[1]
Outflow heaters	A						B[1]
Tracer lines			B	A	B[2] (non-critical only)		B
Jacketed pipes			B[1 6]	A[5]			B[1]

Key:

A - Best choice.
B - Acceptable alternative.

1 - With air vent in parallel.
2 - At end of unlagged cooling leg. Minimum length 1 m.
3 - Use special tracing traps which offer fixed temperature discharge option.
4 - If the equipment is temperature controlled, a condensate pump and trap combination may be required.
5 - With close to steam temperature capsule.
6 - Fitted with anti-air-binding disc.

SELECTING STEAM TRAPS (2)

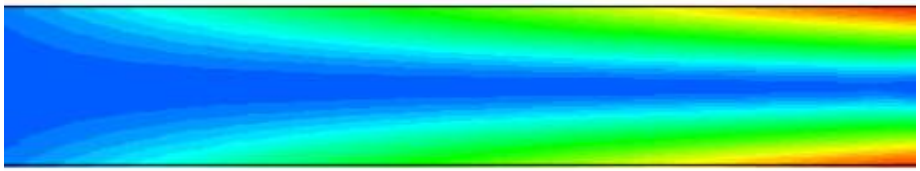
Steam trap:	FT range (float-thermostatic)	FT-C (float-thermostatic with steam release)	TD range (Thermodynamic)	BPT (Balanced pressure thermostatic)	SM (Bimetallic)	No.8 (Liquid expansion)	IB range (Inverted bucket)
Presses							
Multi-platen presses (parallel connections)	B		A[6]				
Multi-platen presses (series connections)			A[1,6]				
Tyre presses	B		B[1]	A			B[1]
Process equipment							
Boiling pans - fixed	A	B	B[1]	B			
Boiling pans - tilting	B	A					
Retorts	A						
Industrial autoclaves	A						B[1]
Digesters	A[1]		B[1]				
Hot tables	B		B[6]	A[2]			
Brewing coppers	A[1]	B					
Evaporators, calandrias	A[1]	B					B[1]
Vulcanisers	A		B[1] (jacket only)				B[1]
Space heating equipment							
Calorifiers	A[4]						
Heater batteries	A[4]						
Radiant panels and strips	A	B[1]	B[1]				B[1]
Radiators and convection cabinets	B			A	B		
Unit heaters and air batteries	A[4]						
Overhead pipe coils	B			A			B[1]

READ DETAIL IN THE REFERENCE

5. STRESSES IN STEAM PIPES

- BENDING STRESS FROM PIPE WEIGHT AND EXTERNAL LOADS
- HOOP STRESS FROM INTERNAL PRESSURE
- THERMAL STRESS

- MATERIAL STRENGTH REDUCES WITH INCREASING TEMPERATURE



ALLOWABLE STRESS

Table 1 Allowable Stresses[a] for Pipe and Tube

ASTM Specification	Grade	Type	Manufacturing Process	Available Sizes, mm	Minimum Tensile Strength, MPa	Basic Allowable Stress S, MPa	Joint Efficiency Factor E	Allowable Stress[b] S_E, MPa	Allowable Stress Range[c] S_A, MPa
A53 Steel	—	F	Cont. Weld	15 to 100	310	77.5	0.6	46.5	117
A53 Steel	B	S	Seamless	15 to 660	413	103	1.0	103	155
A53 Steel	B	E	ERW	50 to 500	413	103	0.85	87.6	155
A106 Steel	B	S	Seamless	15 to 660	413	103	1.0	103	155
B88 Copper	—	—	Hard Drawn	8 to 300	248	62	1.0	62	93.1

[a] Listed stresses are for temperatures to 340°C for steel pipe (to 205°C for Type F) and to 120°C for copper tubing.

[b] To be used for internal pressure stress calculations in Equations (1) and (2).

[c] To be used only for piping flexibility calculations; see Equations (3) and (4).

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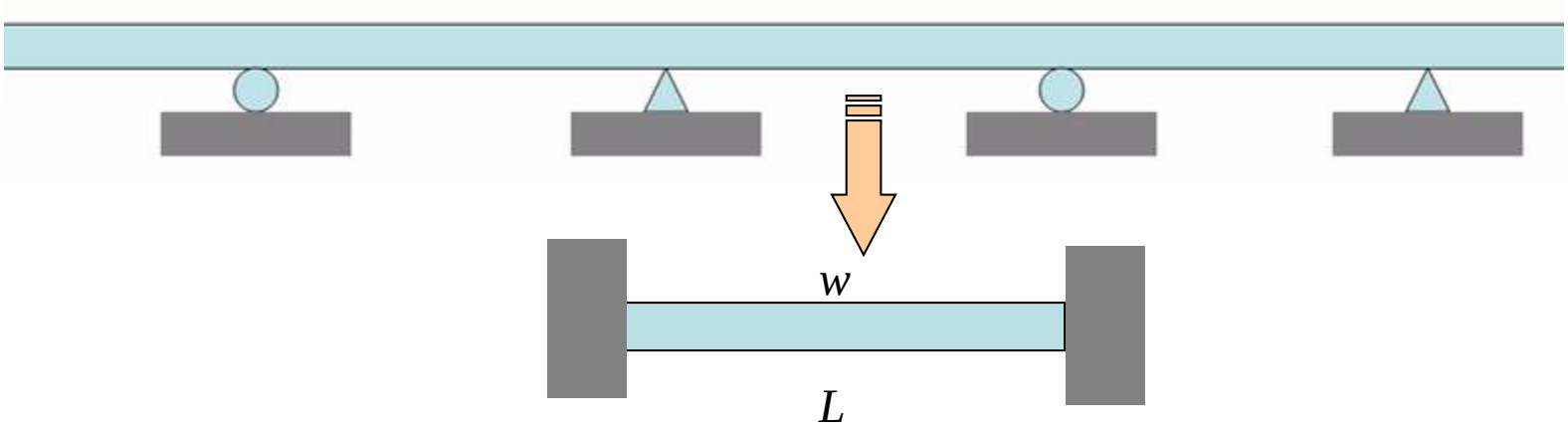
BENDING STRESS



Example : simple calculation

$$\left.\begin{aligned} \frac{S_y}{N_s} &= \frac{\left(\frac{wL^2}{12}\right) r_o}{I} \\ y &= \frac{wL^4}{384EI} \end{aligned}\right\}$$

6” sch 40 pipe carrying steam.
Support interval 5 m.

Bending Stress = 5 MPa
Max. Deflection = 0.02 mm.

RECOMMENDED SUPPORT INTERVAL

Table 6 Suggested Hanger Spacing and Rod Size for Straight Horizontal Runs

Nominal O.D., mm	Hanger Spacing, m			Rod Size, mm
	Standard Steel Pipe[a]		Copper Tube	
	Water	Steam	Water	
15	2.1	2.4	1.5	6.4
20	2.1	2.7	1.5	6.4
25	2.1	2.7	1.8	6.4
40	2.7	3.7	2.4	10
50	3.0	4.0	2.4	10
65	3.4	4.3	2.7	10
80	3.7	4.6	3.0	10
100	4.3	5.2	3.7	13
150	5.2	6.4	4.3	13
200	5.8	7.3	4.9	16
250	6.1	7.9	5.5	19
300	7.0	9.1	5.8	22
350	7.6	9.8		25
400	8.2	10.7		25
450	8.5	11.3		32
500	9.1	11.9		32

Source: Adapted from MSS *Standard* SP-69

[a] Spacing does not apply where span calculations are made or where concentrated loads are placed between supports such as flanges, valves, specialties, etc.

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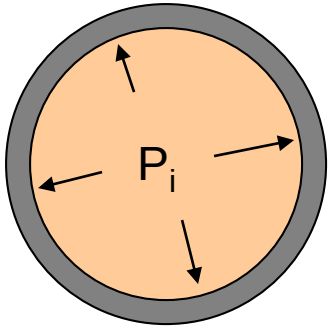
HOOP STRESS



$$\sigma = \frac{P \cdot r}{t}$$

Example:
Steam at 20 bars in 6-inch Sch 40 pipe
Hoop stress = 22.7 MPa

THERMAL STRESS

$$\sigma = E\alpha\Delta T$$

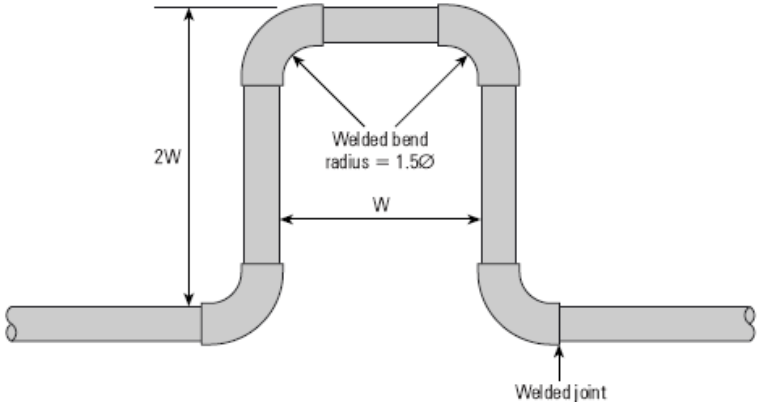
For steel, α = 1.13 x 10^{-5} C^{-1}

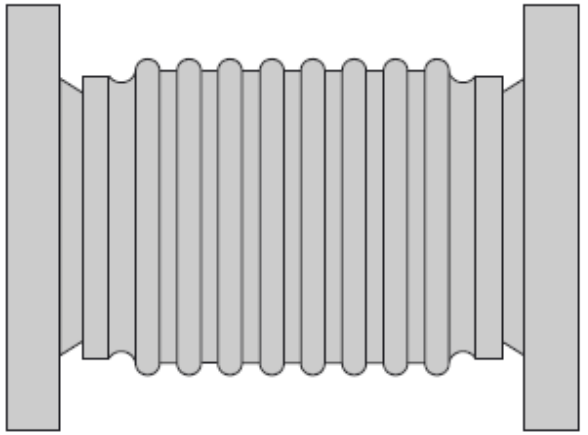
Steam at 20 bars (212 C) will cause the pipe to expand.
1.13x10^{-5} x (212 - 30) = 0.2%
Without proper expansion joint,
theoretical value of thermal stress = 426 MPa

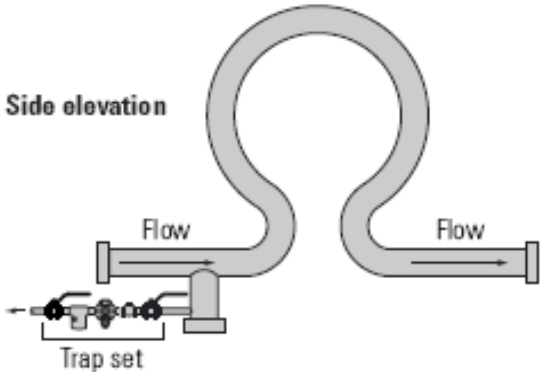
For 6-inch Sch.40 pipe the axial force is equivalent to 156 tons.

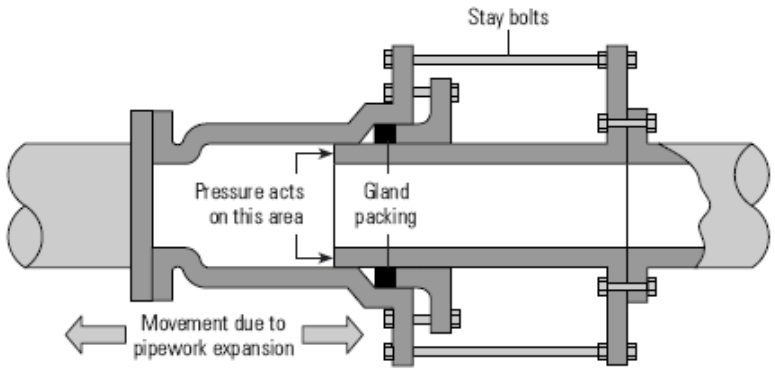
In reality, the support will fail or the pipe will bend and the joints will break.

EXPANSION JOINTS

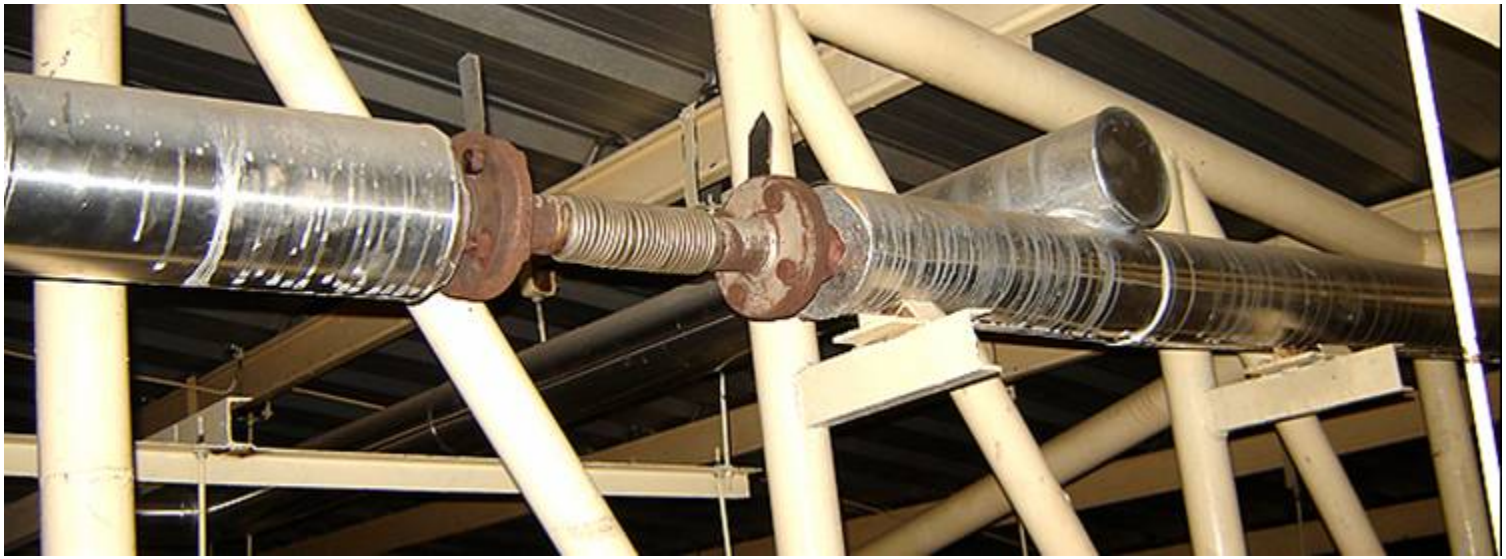








INSTALLATION OF EXPANSION JOINTS



INSTALLATION OF EXPANSION JOINTS