Understanding Steam Drainage Systems

Gene Nelson, P.E.
October 10, 2022

What is the definition of an engineer?

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Someone who solves a problem
you didn't know you had
in a way you don't understand.

$E=MC^2$

Learning Objectives

- Review how piping arrangements affect steam condensate drainage.

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- Understand the parameters behind estimating warm-up loads.
- A better understanding of how pipe size and pitch affect steam condensate drainage capacity.
- Understanding the assumptions used in the current ASHRAE tables for steam condensate pipe sizing.

Agenda

- Description of design issues

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- Pressure cascade in steam condensate drainage systems

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- Air venting and vacuum release

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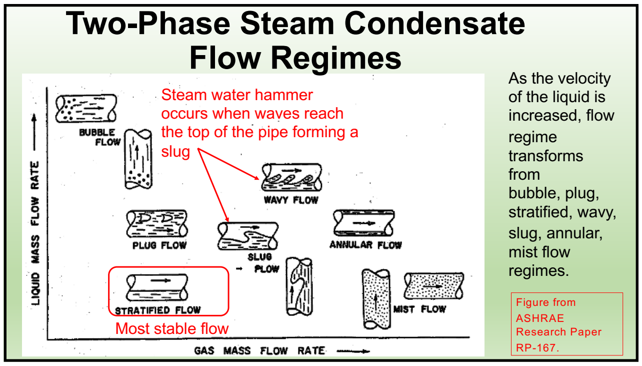
- Pressure cascade in steam condensate drainage systems
- Air venting and vacuum release
- Pipe sizing criteria considerations

Design Issues

- Steam Water Hammer
  - Slugs of liquid water are accelerated to steam velocities until a slug of water hits a 90^o fitting or other in-line obstacles.
  - Rapid change in momentum results in a BANG!!
  https://www.youtube.com/watch?v=Wvzpxcgw-XE
  - Damage to pipe supports and steam traps is a real concern.



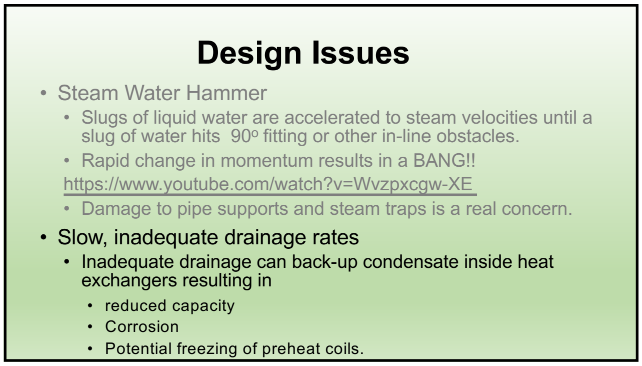
Two-Phase Steam Condensate Flow Regimes

Steam water hammer occurs when waves reach the top of the pipe forming a slug

Most stable flow

As the velocity of the liquid is increased, flow regime transforms from bubble, plug, stratified, wavy, slug, annular, mist flow regimes.

Figure from ASHRAE Research Paper RP-167.



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  - Rapid change in momentum results in a BANG!!

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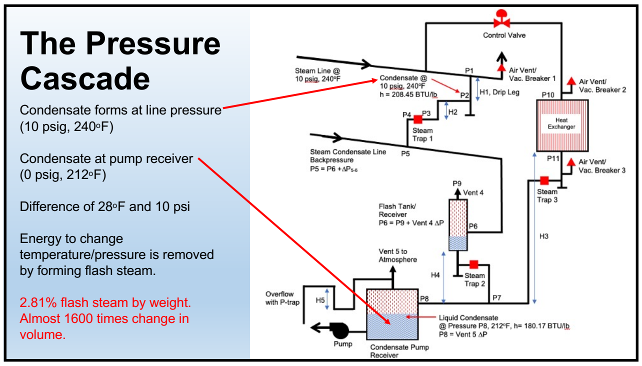
  - Damage to pipe supports and steam traps is a real concern.
- Slow, inadequate drainage rates
  - Inadequate drainage can back-up condensate inside heat exchangers resulting in
    - reduced capacity
    - Corrosion
    - Potential freezing of preheat coils.



The Pressure Cascade

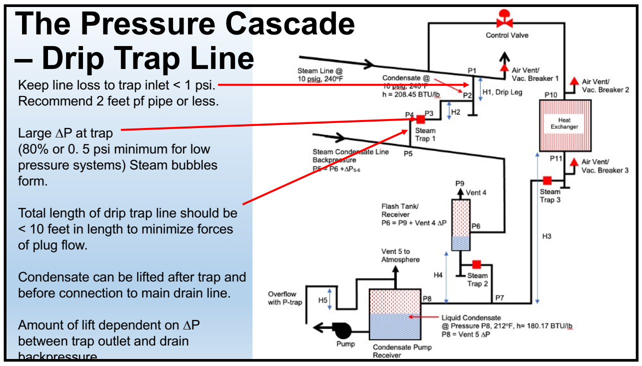
Condensate forms at line pressure (10 psig, 240ºF)

Condensate at pump receiver (0 psig, 212ºF)

Difference of 28ºF and 10 psi

Energy to change temperature/pressure is removed by forming flash steam.

2.81% flash steam by weight. Almost 1600 times change in volume.



The Pressure Cascade – Drip Trap Line

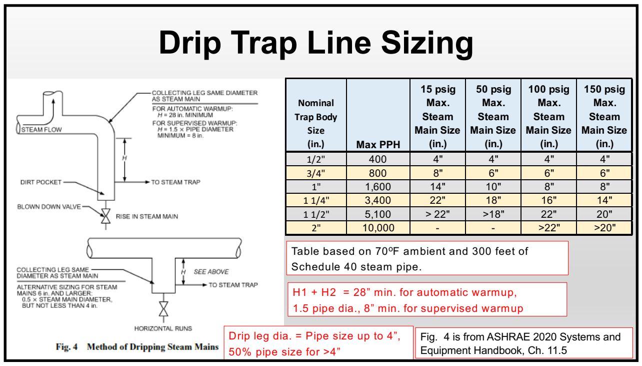
Keep line loss to trap inlet < 1 psi. Recommend 2 feet pf pipe or less.

Large ΔP at trap (80% or 0. 5 psi minimum for low pressure systems) Steam bubbles form.

Total length of drip trap line should be < 10 feet in length to minimize forces of plug flow.

Condensate can be lifted after trap and before connection to main drain line.

Amount of lift dependent on ΔP between trap outlet and drain backpressure



Drip Trap Line Sizing

Fig. 4 Method of Dripping Steam Mains

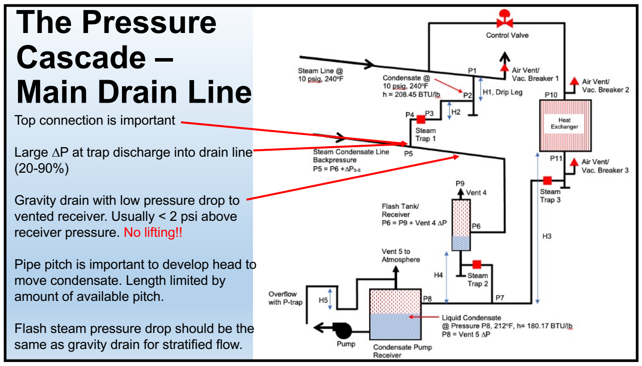
Nominal Trap Body Size (in.)	Max PPH	15 psig Max. Steam Main Size (in.)	50 psig Max. Steam Main Size (in.)	100 psig Max. Steam Main Size (in.)	150 psig Max. Steam Main Size (in.)
1/2"	400	4"	4"	4"	4"
3/4"	800	8"	6"	6"	6"
1"	1,600	14"	10"	8"	8"
1 1/4"	3,400	22"	18"	16"	14"
1 1/2"	5,100	> 22"	>18"	22"	20"
2"	10,000	-	-	>22"	>20"

Table based on 70ºF ambient and 300 feet of Schedule 40 steam pipe.

H1 + H2 = 28" min. for automatic warmup, 1.5 pipe dia., 8" min. for supervised warmup

Drip leg dia. = Pipe size up to 4", 50% pipe size for >4"

Fig. 4 is from ASHRAE 2020 Systems and Equipment Handbook, Ch. 11.5



The Pressure Cascade – Main Drain Line

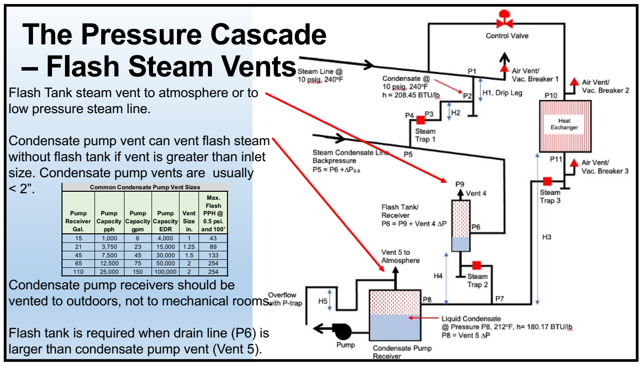
Top connection is important

Large ΔP at trap discharge into drain line (20-90%)

Gravity drain with low pressure drop to vented receiver. Usually < 2 psi above receiver pressure. No lifting!!

Pipe pitch is important to develop head to move condensate. Length limited by amount of available pitch.

Flash steam pressure drop should be the same as gravity drain for stratified flow.



The Pressure Cascade – Flash Steam Vents

Flash Tank steam vent to atmosphere or to low pressure steam line.

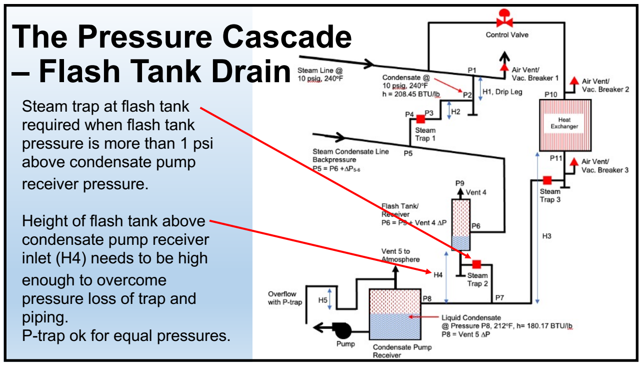
Condensate pump vent can vent flash steam without flash tank if vent is greater than inlet size. Condensate pump vents are usually < 2”.

Common Condensate Pump Vent Sizes

Pump Receiver Gal.	Pump Capacity pph	Pump Capacity gpm	Pump Capacity EDR	Vent Size in.	Max. Flash PPH @ 0.5 psi. and 100'
15	1,000	6	4,000	1	43
21	3,750	23	15,000	1.25	89
45	7,500	45	30,000	1.5	133
65	12,500	75	50,000	2	254
110	25,000	150	100,000	2	254

Condensate pump receivers should be vented to outdoors, not to mechanical rooms.

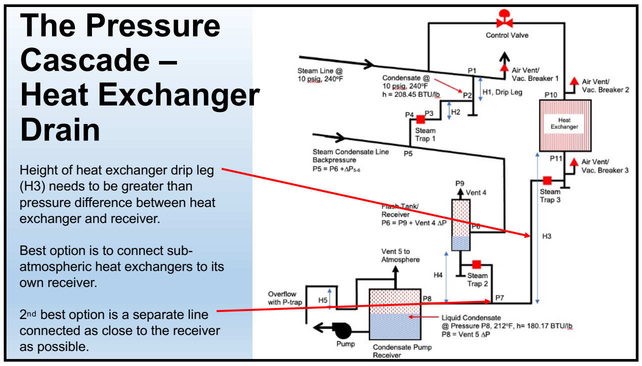
Flash tank is required when drain line (P6) is larger than condensate pump vent (Vent 5).



The Pressure Cascade – Flash Tank Drain

Steam trap at flash tank required when flash tank pressure is more than 1 psi above condensate pump receiver pressure.

Height of flash tank above condensate pump receiver inlet (H4) needs to be high enough to overcome pressure loss of trap and piping.
P-trap ok for equal pressures.

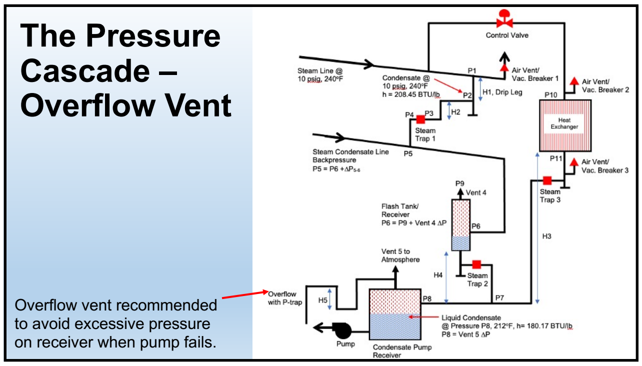


The Pressure Cascade – Heat Exchanger Drain

Height of heat exchanger drip leg (H3) needs to be greater than pressure difference between heat exchanger and receiver.

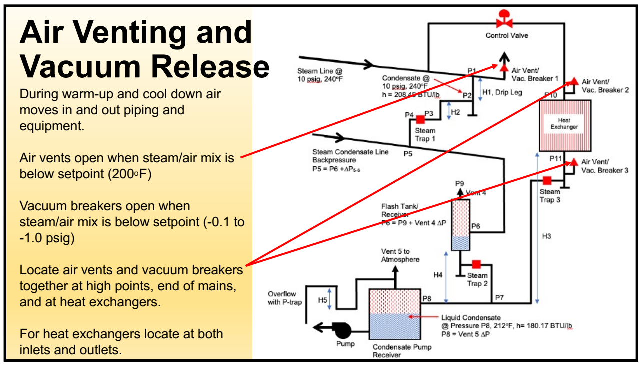
Best option is to connect sub-atmospheric heat exchangers to its own receiver.

2nd best option is a separate line connected as close to the receiver as possible.



The Pressure Cascade – Overflow Vent

Overflow vent recommended to avoid excessive pressure on receiver when pump fails.



Air Venting and Vacuum Release

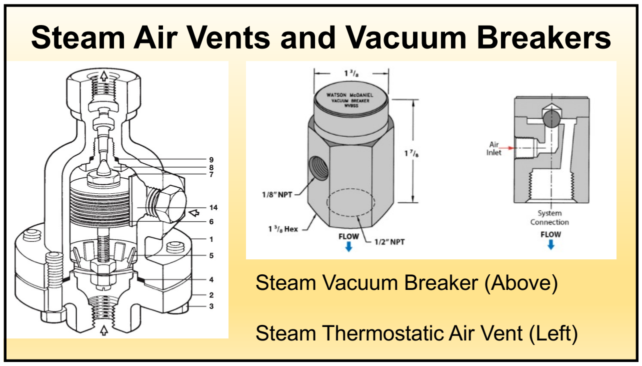
During warm-up and cool down air moves in and out piping and equipment.

Air vents open when steam/air mix is below setpoint (200°F)

Vacuum breakers open when steam/air mix is below setpoint (-0.1 to -1.0 psig)

Locate air vents and vacuum breakers together at high points, end of mains, and at heat exchangers.

For heat exchangers locate at both inlets and outlets.



Steam Air Vents and Vacuum Breakers

Steam Vacuum Breaker (Above)

Steam Thermostatic Air Vent (Left)

Air Venting and Vacuum Release

- During start-up air should be purged from system to obtain design steam temperatures.

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- During start-up air should be purged from system to obtain design steam temperatures.
- During cool-down re-introducing air to break the vacuum can reduce the required head pressure to drain systems. 15 psig = 36 feet of head at 212^{o}F.

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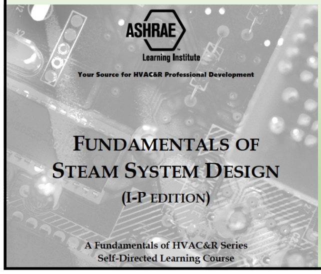
- F&T steam traps have limited capacity to vent air.
- Vacuum breakers have a minimum ΔP to open (0.1 to 1 psid)

Steam Condensate Pipe Sizing

Required Inputs

- Mass flow based on warmup loads (pounds per hour or pph)

Design Flow Rates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Self-Directed Learning Course

- Sources
  - ASHRAE
  - Steam Trap Manufacturers

Table 6-1 Recommended Steam Trap Selections and Safety Factors

Application	Trap Selection	Safety Factor
Boiler Header	Inverted Bucket, F&T	1.5
Steam Mains & Branch Lines	Inverted Bucket, F&T, Thermostatic	3
Steam Separator	Inverted Bucket	3
Tracer Lines	Inverted Bucket, Thermostatic	2
Unit Heaters & Air Handlers	Inverted Bucket, F&T	3
Finned Radiation & Pipe Coils	Inverted Bucket, F&T, Thermostatic	3
Processor Air Heaters	Inverted Bucket, F&T	2 - 3
Shell and Tube Heat Exchangers	Inverted Bucket, F&T	2
Flash Tank	Inverted Bucket, F&T	3

Source: ASHRAE, Systems and Equipment, Page 10.8

Drip Traps Design Flow Rates

- Steady State Flows based on heat loss to ambient.
- Warm-up loads = steady state flows x safety factor of 3.

Table CG-10. Condensation in Insulated Pipes Carrying in Quiet Air at 70°F (Insulation assumed to be 75% efficient.)

Pressure, psig		15	30	60	125	180	250	450	600	900
Pipe Size (in)	sq ft Per Lineal ft	Pounds of Condensate Per Hour Per Lineal Foot								
1	.344	.05	.06	.07	.10	.12	.14	.186	.221	.289
1-1/4	.434	.06	.07	.09	.12	.14	.17	.231	.273	.359
1-1/2	**.497**	**.07**	**.08**	**.10**	**.14**	**.16**	**.19**	**.261**	**.310**	**.406**
2	.622	.08	.10	.13	.17	.20	.23	.320	.379	.498
2-1/2	.753	.10	.12	.15	.20	.24	.28	.384	.454	.596
3	**.916**	**.12**	**.14**	**.18**	**.24**	**.28**	**.33**	**.460**	**.546**	**.714**
3-1/2	1.047	.13	.16	.20	.27	.32	.38	.520	.617	.807
4	1.178	.15	.18	.22	.30	.36	.43	.578	.686	.897
5	**1.456**	**.18**	**.22**	**.27**	**.37**	**.44**	**.51**	**.698**	**.826**	**1.078**
6	1.735	.20	.25	.32	.44	.51	.59	.809	.959	1.253
8	2.260	.27	.32	.41	.55	.66	.76	1.051	1.244	1.628

Table data from manufacturer 'A". Manufacturer "S" slightly different.
Q (lbs/hr) = Safety factor x surface area (sf) x insulation u-factor (BTU/hr-sf-ºF) x (T_{steam} - $T_{ambient}$)/ latent heat of steam (BTU/lb_m)

Drip Trap Design Flow Rates – Thermal Energy Model

- Based on
  - Mass (weight of pipe)
  - Temperature change between steam and ambient temperature
  - Specific heat of pipe
  - Time (most models assume 1 hour)
  - Most models do not account for air purge

Table CG-11. The Warming-Up Load from 70°F, Schedule 40 Pipe

Pressure, psig		2	15	30	60	125	180	250
Pipe Size (in)	wt of Pipe Per ft (lbs)	Pounds of Condensate Per Lineal Foot						
1	1.69	.030	.037	.043	.051	.063	.071	.079
1-1/4	2.27	.040	.050	.057	.068	.085	.095	.106
1-1/2	**2.72**	**.048**	**.059**	**.069**	**.082**	**.101**	**.114**	**.127**
2	3.65	.065	.080	.092	.110	.136	.153	.171
2-1/2	5.79	.104	.126	.146	.174	.215	.262	.271
3	**7.57**	**.133**	**.165**	**.190**	**.227**	**.282**	**.316**	**.354**
3-1/2	9.11	.162	.198	.229	.273	.339	.381	.426
4	10.79	.190	.234	.271	.323	.400	.451	.505
5	**14.62**	**.258**	**.352**	**.406**	**.439**	**.544**	**.612**	**.684**
6	18.97	.335	.413	.476	.569	.705	.795	.882
8	28.55	.504	.320	.720	.860	1.060	1.190	1.340

Table data from manufacturer 'A".
Q (lbs/hr) = Safety factor x pipe mass (lbs) x pipe specific heat (BTU/lb-ºF) x (T_{steam} - $T_{ambient}$)/ latent heat of steam (BTU/lb_m)/ 1 hour

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Steam Condensate Pipe Sizing

Required Inputs

- Mass flow based on warmup loads (pounds per hour or pph)
- Amount of flash steam (x%, pph) based on
  - Supply steam pressure (psig)
  - Receiver pressure (psig)
  - Steam Tables and ASHRAE Equation 25

Calculate Flash Steam Flow Using Steam Tables

Add atmospheric pressure to get psia

Absolute Pressure (psia)	Saturated Temperature (°F)	Liquid Specific Volume (ft3/Lb)	Vapor Specific Volume (ft3/Lb)	Liquid Enthalpy (BTU/lb)	Vapor Enthalpy (BTU/lb)
15	213.0	0.016726	26.29	181.21	1150.9
16	216.3	0.016749	24.76	184.51	1152.11
17	219.7	0.016771	23.28	187.90	1153.28
18	222.4	0.016793	22.20	190.63	1154.29
19	225.2	0.015769	21.14	193.45	1155.30
20	228.0	0.013435	20.09	196.27	1156.3
21	230.5	0.015598	19.21	198.87	1157.25
22	232.9	0.016872	18.43	201.27	1158.12
23	235.5	0.016891	17.63	203.87	1159.02
24	237.8	0.016909	16.96	206.21	1159.83
25	240.1	0.016927	16.30	208.52	1160.6
26	242.2	0.016944	15.73	210.70	1161.37
27	244.2	0.016961	15.21	212.71	1162.07
28	246.4	0.016977	14.68	214.92	1162.83
29	248.4	0.016993	14.19	216.96	1163.52
30	250.3	0.017008	13.74	218.93	1164.1

v_{f1} = 0.017008 ft^3/lb_m
v_{g2} = 26.29 ft^3/lb_m

Large Δ (1553 times) between liquid and vapor specific volumes and densities

ASHRAE Handbook of Fundamentals, Chapter 22, Equation 25:

X (% flash steam) =
(h_{f1} – h_{f2})/(h_{g2} – h_{f2})

where

Enthalpy h_{f1} is at trap inlet
Enthalpy h_{f2}, h_{g2} are at the outlet (vented receiver).

For 15 psig supply and 0 psig @ receiver

X % = (218.93 – 181.21) / (1150.9 – 181.21) = **3.89% by mass**

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  - Supply steam pressure (psig)
  - Receiver pressure (psig)
  - Steam Tables and ASHRAE Equation 25
- Amount of available pitch to determine friction rate
  - When using ASHRAE tables, use 1/16 psi/100 ft ΔP for most systems with pitch <1" per 14 ft.

Friction Rates Based on Liquid

Pressure drop in drainage systems is based on gravity or the head pressure in the piping system.

ΔP_{liquid} (psi, kPa) = $\Delta H \bullet \rho$ /144 in^2/ft^2 (0.433 psi per foot @ 62.4 lbs/ft^3 or 2.31 feet per psi with 62.4 lbs./ft^3)

Where

ΔH = head pressure or liquid height (ft) or
pipe slope (s, %, in/ft/12 in/ft) x total horizontal pipe length (ft)

ρ = liquid density at the receiver (lb/ft^3, kg/m^3) or
ρ = 1/specific volume v_{liquid} (ft^3/lb, m^3/kg)

Pressure drop of liquid and steam should be the same to avoid waves and slug flow.

Liquid Friction Rates

	Slope (in./10 feet)	Slope %	Δpsi /100 feet
	0.090	0.08%	1/32 (1/2 oz.)
	0.120	0.10%	1/24 (2/3 oz.)
	0.181	0.15%	1/16 (1 oz.)
1" per 40 ft.	0.25	0.21%	0.09
1" per 20 ft.	0.5	0.42%	0.17
1" per 14 ft.	0.723	0.60%	1/4 (4 oz.)
	1	0.83%	0.35
	1.445	1.20%	1/2 (8 oz.)
	1.5	1.25%	0.52
	2	1.67%	0.69
	2.89	2.41%	1 (16 oz.)

Yellow values are used by ASHRAE tables.

Use 1/16 psi/100 ft w/ ASHRAE tables

Using condensate density of 59.79 lb/ft^3 at 212ºF and 14.69 psia the equation can be shortened to:

Δpsi/100 ft = 0.346 • slope (in/10 ft)

Or slope (in/10 ft) = 2.89 • psi/100ft

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  - Supply steam pressure (psig)
  - Receiver pressure (psig)
  - Steam Tables and ASHRAE Equation 25
- Amount of available pitch to determine friction rate
  - When using ASHRAE tables, use 1/16 psi/100 ft ΔP for most systems with pitch <1" per 14 ft.
- Selection tables or calculations

ASHRAE Tables 34-37
for Steam Condensate Pipe Sizing

Tables from 2021 ASHRAE Handbook of Fundamentals, Chapter 22, pp 35-37

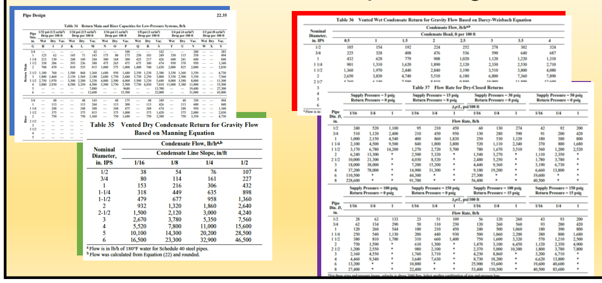


Table 35 Vented Dry Condensate Return for Gravity Flow Based on Manning Equation

Nominal Diameter, in. IPS	Condensate Flow, lb/h^{a,b} Condensate Line Slope, in/ft 1/16	1/8	1/4	1/2
1/2	38	54	76	107
3/4	80	114	161	227
1	153	216	306	432
1-1/4	318	449	635	898
1-1/2	479	677	958	1,360
2	932	1,320	1,860	2,640
2-1/2	1,500	2,120	3,000	4,240
3	2,670	3,780	5,350	7,560
4	5,520	7,800	11,000	15,600
5	10,100	14,300	20,200	28,500
6	16,500	23,300	32,900	46,500

^{a} Flow is in lb/h of 180°F water for Schedule 40 steel pipes.
^{b} Flow was calculated from Equation (22) and rounded.

Table 36 Vented Wet Condensate Return for Gravity Flow Based on Darcy-Weisbach Equation

Nominal Diameter, in. IPS	Condensate Flow, lb/h^{a,b} Condensate Head, ft per 100 ft 0.5	1	1.5	2	2.5	3	3.5	4
1/2	105	154	192	224	252	278	302	324
3/4	225	328	408	476	536	590	640	687
1	432	628	779	908	1,020	1,120	1,220	1,310
1 1/4	901	1,310	1,620	1,890	2,120	2,330	2,530	2,710
1 1/2	1,360	1,970	2,440	2,840	3,190	3,510	3,800	4,080
2	2,650	3,830	4,740	5,510	6,180	6,800	7,360	7,890
2 1/2								
3								
4								
5								
6								

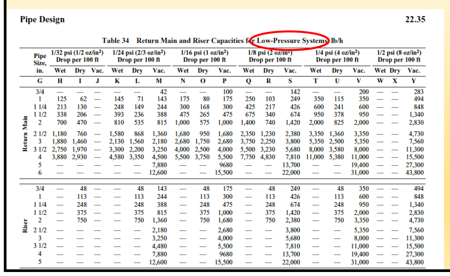
Table 37 Flow Rate for Dry-Closed Returns

Pipe Dia. D, in.	Supply Pressure = 5 psig Return Pressure = 0 psig 1/16	1/4	1	Supply Pressure = 15 psig Return Pressure = 0 psig 1/16	1/4	1	Supply Pressure = 30 psig Return Pressure = 0 psig 1/16	1/4	1	Supply Pressure = 50 psig Return Pressure = 0 psig 1/16	1/4	1
	Δp/L, psi/100 ft; Flow Rate, lb/h											
1/2	240	520	1,100	95	210	450	60	130	274	42	92	200
3/4	510	1,120	2,400	210	450	950	130	280	590	91	200	420
1	1,000	2,150	4,540	400	860	1,820	250	530	1,120	180	380	800
1 1/4	2,100	4,500	9,500	840	1,800	3,800	520	1,110	2,340	370	800	1,680
1 1/2	3,170	6,780	14,200	1,270	2,720	5,700	780	1,670	3,510	560	1,200	2,520
2	6,240	13,300	*	2,500	5,320	*	1,540	3,270	*	1,110	2,350	*
2 1/2	10,000	21,300	*	4,030	8,520	*	2,480	5,250	*	1,780	3,780	*
3	18,000	38,000	*	7,200	15,200	*	4,440	9,360	*	3,190	6,730	*
4	37,200	78,000	*	14,900	31,300	*	9,180	19,200	*	6,660	13,800	*
6	110,500	*	*	44,300	*	*	27,300	*	*	19,600	*	*
8	228,600	*	*	91,700	*	*	56,400	*	*	40,500	*	*

Pipe Dia. D, in.	Supply Pressure = 100 psig Return Pressure = 0 psig 1/16	1/4	1	Supply Pressure = 150 psig Return Pressure = 0 psig 1/16	1/4	1	Supply Pressure = 100 psig Return Pressure = 15 psig 1/16	1/4	1	Supply Pressure = 150 psig Return Pressure = 15 psig 1/16	1/4	1
	Δp/L, psi/100 ft; Flow Rate, lb/h											
1/2	28	62	133	23	51	109	56	120	260	43	93	200
3/4	62	134	290	50	110	230	120	260	560	93	200	420
1	120	260	544	100	210	450	240	500	1,060	180	390	800
1 1/4	250	540	1,130	200	440	930	500	1,060	2,200	380	800	1,680
1 1/2	380	810	1,700	310	660	1,400	750	1,600	3,320	570	1,210	2,500
2	750	1,590	*	610	1,300	*	1,470	3,100	6,450	1,120	2,350	4,900
2 1/2	1,200	2,550	*	980	2,100	*	2,370	5,000	10,300	1,800	3,780	7,800
3	2,160	4,550	*	1,760	3,710	*	4,230	8,860	*	3,200	6,710	*
4	4,460	9,340	*	3,640	7,630	*	8,730	18,200	*	6,620	13,800	*
6	13,200	*	*	10,800	*	*	25,900	53,600	*	19,600	40,600	*
8	27,400	*	*	22,400	*	*	53,400	110,300	*	40,500	83,600	*

*For these sizes and pressure losses, velocity is above 7000 fpm. Select another combination of size and pressure loss.

ASHRAE Table 34
for Low Pressure Pipe Sizing Criteria

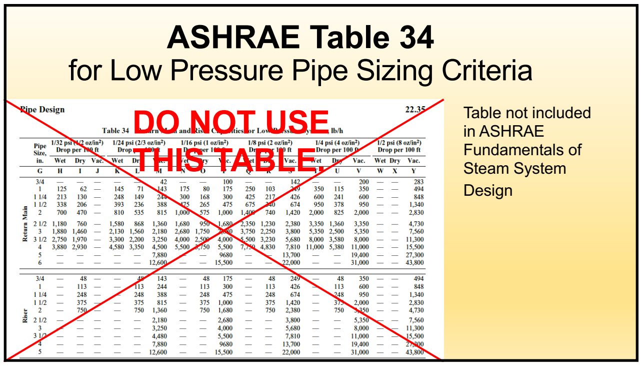


Pipe Design 22.35

Table 34 Return Main and Riser Capacities for Low-Pressure Systems, lb/h

	Pipe Size, in.	1/32 psi (1/2 oz/in^2) Drop per 100 ft Wet	Dry	Vac.	1/24 psi (2/3 oz/in^2) Drop per 100 ft Wet	Dry	Vac.	1/16 psi (1 oz/in^2) Drop per 100 ft Wet	Dry	Vac.	1/8 psi (2 oz/in^2) Drop per 100 ft Wet	Dry	Vac.	1/4 psi (4 oz/in^2) Drop per 100 ft Wet	Dry	Vac.	1/2 psi (8 oz/in^2) Drop per 100 ft Wet	Dry	Vac.
	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Return Main	3/4	—	—	—	—	—	42	—	—	100	—	—	142	—	—	200	—	—	283
	1	125	62	—	145	71	143	175	80	175	250	103	249	350	115	350	—	—	494
	1 1/4	213	130	—	248	149	244	300	168	300	425	217	426	600	241	600	—	—	848
	1 1/2	338	206	—	393	236	388	475	265	475	675	340	674	950	378	950	—	—	1,340
	2	700	470	—	810	535	815	1,000	575	1,000	1,400	740	1,420	2,000	825	2,000	—	—	2,830
	2 1/2	1,180	760	—	1,580	868	1,360	1,680	950	1,680	2,350	1,230	2,380	3,350	1,360	3,350	—	—	4,730
	3	1,880	1,460	—	2,130	1,560	2,180	2,680	1,750	2,680	3,750	2,250	3,800	5,350	2,500	5,350	—	—	7,560
	3 1/2	2,750	1,970	—	3,300	2,200	3,250	4,000	2,500	4,000	5,500	3,230	5,680	8,000	3,580	8,000	—	—	11,300
	4	3,880	2,930	—	4,580	3,350	4,500	5,500	3,750	5,500	7,750	4,830	7,810	11,000	5,380	11,000	—	—	15,500
	5	—	—	—	—	—	7,880	—	—	9680	—	—	13,700	—	—	19,400	—	—	27,300
	6	—	—	—	—	—	12,600	—	—	15,500	—	—	22,000	—	—	31,000	—	—	43,800
Riser	3/4	—	48	—	—	48	143	—	48	175	—	48	249	—	48	350	—	—	494
	1	—	113	—	—	113	244	—	113	300	—	113	426	—	113	600	—	—	848
	1 1/4	—	248	—	—	248	388	—	248	475	—	248	674	—	248	950	—	—	1,340
	1 1/2	—	375	—	—	375	815	—	375	1,000	—	375	1,420	—	375	2,000	—	—	2,830
	2	—	750	—	—	750	1,360	—	750	1,680	—	750	2,380	—	750	3,350	—	—	4,730
	2 1/2	—	—	—	—	—	2,180	—	—	2,680	—	—	3,800	—	—	5,350	—	—	7,560
	3	—	—	—	—	—	3,250	—	—	4,000	—	—	5,680	—	—	8,000	—	—	11,300
	3 1/2	—	—	—	—	—	4,480	—	—	5,500	—	—	7,810	—	—	11,000	—	—	15,500
	4	—	—	—	—	—	7,880	—	—	9680	—	—	13,700	—	—	19,400	—	—	27,300
	5	—	—	—	—	—	12,600	—	—	15,500	—	—	22,000	—	—	31,000	—	—	43,800

- For very low pressure residential systems (< 2 psig assumed)
- Vacuum systems close to wet system capacities.
- Risers have increased capacities. (Reduced pipe sizes are not recommended due to hydraulic jump issues.)
- Not useful for most commercial steam systems



ASHRAE Table 34
for Low Pressure Pipe Sizing Criteria

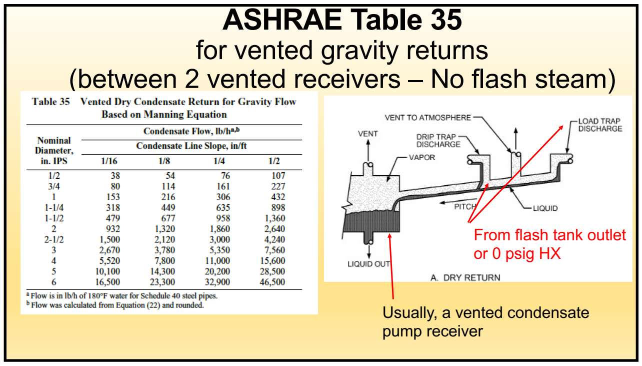
Pipe Design 22.35

DO NOT USE THIS TABLE.

Table 34 Return Main and Riser Capacities for Low-Pressure Systems, lb/h

	Pipe Size, in.	1/32 psi (1/2 oz/in²) Drop per 100 ft			1/24 psi (2/3 oz/in²) Drop per 100 ft			1/16 psi (1 oz/in²) Drop per 100 ft			1/8 psi (2 oz/in²) Drop per 100 ft			1/4 psi (4 oz/in²) Drop per 100 ft			1/2 psi (8 oz/in²) Drop per 100 ft		
		Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.
	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Return Main	3/4	—	—	—	—	—	42	—	—	100	—	—	142	—	—	200	—	—	283
	1	125	62	—	145	71	143	175	80	175	250	103	249	350	115	350	—	—	494
	1 1/4	213	130	—	248	149	244	300	168	300	425	217	426	600	241	600	—	—	848
	1 1/2	338	206	—	393	236	388	475	265	475	675	340	674	950	378	950	—	—	1,340
	2	700	470	—	810	535	815	1,000	575	1,000	1,400	740	1,420	2,000	825	2,000	—	—	2,830
	2 1/2	1,180	760	—	1,580	868	1,360	1,680	950	1,680	2,350	1,230	2,380	3,350	1,360	3,350	—	—	4,730
	3	1,880	1,460	—	2,130	1,560	2,180	2,680	1,750	2,680	3,750	2,250	3,800	5,350	2,500	5,350	—	—	7,560
	3 1/2	2,750	1,970	—	3,300	2,200	3,250	4,000	2,500	4,000	5,500	3,230	5,680	8,000	3,580	8,000	—	—	11,300
	4	3,880	2,930	—	4,580	3,350	4,500	5,500	3,750	5,500	7,750	4,830	7,810	11,000	5,380	11,000	—	—	15,500
	5	—	—	—	—	—	7,880	—	—	9680	—	—	13,700	—	—	19,400	—	—	27,300
	6	—	—	—	—	—	12,600	—	—	15,500	—	—	22,000	—	—	31,000	—	—	43,800
Riser	3/4	—	48	—	—	48	143	—	48	175	—	48	249	—	48	350	—	—	494
	1	—	113	—	—	113	244	—	113	300	—	113	426	—	113	600	—	—	848
	1 1/4	—	248	—	—	248	388	—	248	475	—	248	674	—	248	950	—	—	1,340
	1 1/2	—	375	—	—	375	815	—	375	1,000	—	375	1,420	—	375	2,000	—	—	2,830
	2	—	750	—	—	750	1,360	—	750	1,680	—	750	2,380	—	750	3,350	—	—	4,730
	2 1/2	—	—	—	—	—	2,180	—	—	2,680	—	—	3,800	—	—	5,350	—	—	7,560
	3	—	—	—	—	—	3,250	—	—	4,000	—	—	5,680	—	—	8,000	—	—	11,300
	3 1/2	—	—	—	—	—	4,480	—	—	5,500	—	—	7,810	—	—	11,000	—	—	15,500
	4	—	—	—	—	—	7,880	—	—	9680	—	—	13,700	—	—	19,400	—	—	27,300
	5	—	—	—	—	—	12,600	—	—	15,500	—	—	22,000	—	—	31,000	—	—	43,800

Table not included in ASHRAE Fundamentals of Steam System Design



ASHRAE Table 35
for vented gravity returns
(between 2 vented receivers – No flash steam)

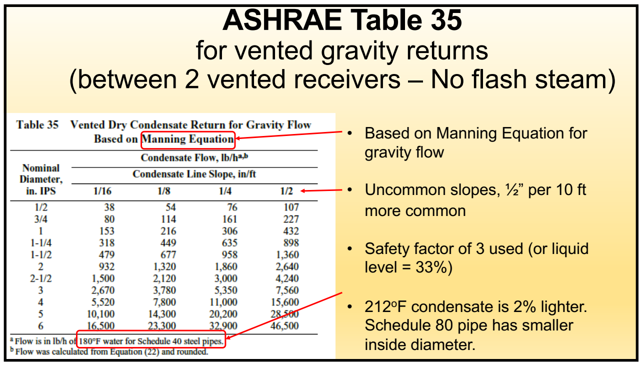
Table 35 Vented Dry Condensate Return for Gravity Flow Based on Manning Equation

Nominal Diameter, in. IPS	Condensate Flow, lb/h[a,b]			
	Condensate Line Slope, in/ft			
	1/16	1/8	1/4	1/2
1/2	38	54	76	107
3/4	80	114	161	227
1	153	216	306	432
1-1/4	318	449	635	898
1-1/2	479	677	958	1,360
2	932	1,320	1,860	2,640
2-1/2	1,500	2,120	3,000	4,240
3	2,670	3,780	5,350	7,560
4	5,520	7,800	11,000	15,600
5	10,100	14,300	20,200	28,500
6	16,500	23,300	32,900	46,500

[a] Flow is in lb/h of 180°F water for Schedule 40 steel pipes.
[b] Flow was calculated from Equation (22) and rounded.

From flash tank outlet or 0 psig HX

Usually, a vented condensate pump receiver



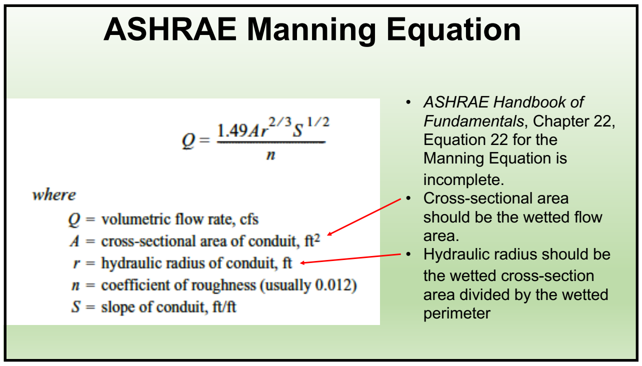
ASHRAE Table 35
for vented gravity returns
(between 2 vented receivers – No flash steam)

Table 35 Vented Dry Condensate Return for Gravity Flow Based on Manning Equation

Nominal Diameter, in. IPS	Condensate Flow, lb/h[a,b]			
	Condensate Line Slope, in/ft			
	1/16	1/8	1/4	1/2
1/2	38	54	76	107
3/4	80	114	161	227
1	153	216	306	432
1-1/4	318	449	635	898
1-1/2	479	677	958	1,360
2	932	1,320	1,860	2,640
2-1/2	1,500	2,120	3,000	4,240
3	2,670	3,780	5,350	7,560
4	5,520	7,800	11,000	15,600
5	10,100	14,300	20,200	28,500
6	16,500	23,300	32,900	46,500

[a] Flow is in lb/h of 180°F water for Schedule 40 steel pipes.
[b] Flow was calculated from Equation (22) and rounded.

- Based on Manning Equation for gravity flow
- Uncommon slopes, ½" per 10 ft more common
- Safety factor of 3 used (or liquid level = 33%)
- 212°F condensate is 2% lighter. Schedule 80 pipe has smaller inside diameter.



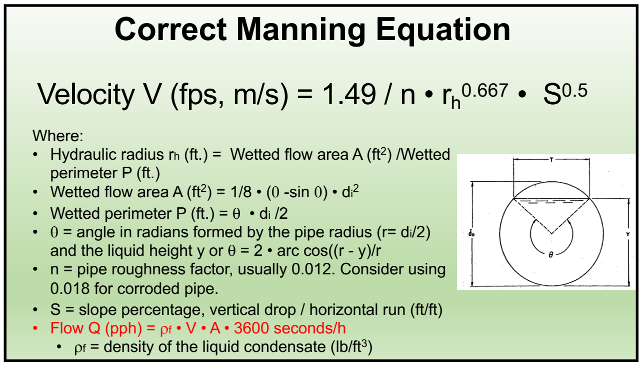
ASHRAE Manning Equation

$$Q = \frac{1.49 A r^{2/3} S^{1/2}}{n}$$

where

Q = volumetric flow rate, cfs
A = cross-sectional area of conduit, ft²
r = hydraulic radius of conduit, ft
n = coefficient of roughness (usually 0.012)
S = slope of conduit, ft/ft

- *ASHRAE Handbook of Fundamentals*, Chapter 22, Equation 22 for the Manning Equation is incomplete.
- Cross-sectional area should be the wetted flow area.
- Hydraulic radius should be the wetted cross-section area divided by the wetted perimeter

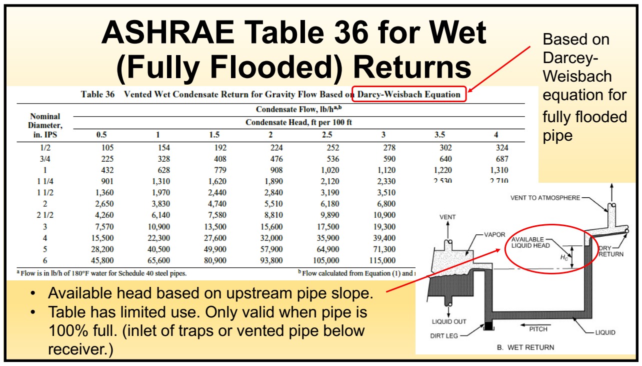


Correct Manning Equation

Velocity V (fps, m/s) = $1.49 / n \cdot r_h^{0.667} \cdot S^{0.5}$

Where:

- Hydraulic radius r_h (ft.) = Wetted flow area A (ft²) /Wetted perimeter P (ft.)
- Wetted flow area A (ft²) = $1/8 \cdot (\theta - \sin\theta) \cdot d_i^2$
- Wetted perimeter P (ft.) = $\theta \cdot d_i/2$
- θ = angle in radians formed by the pipe radius ($r = d_i/2$) and the liquid height y or $\theta = 2 \cdot \arccos((r - y)/r$
- n = pipe roughness factor, usually 0.012. Consider using 0.018 for corroded pipe.
- S = slope percentage, vertical drop / horizontal run (ft/ft)
- Flow Q (pph) = $\rho_f \cdot V \cdot A \cdot 3600$ seconds/h
  - ρ_f = density of the liquid condensate (lb/ft³)



ASHRAE Table 36 for Wet (Fully Flooded) Returns

Table 36 Vented Wet Condensate Return for Gravity Flow Based on Darcy-Weisbach Equation

Nominal Diameter, in. IPS	Condensate Flow, lb/h[a,b]							
	Condensate Head, ft per 100 ft							
	0.5	1	1.5	2	2.5	3	3.5	4
1/2	105	154	192	224	252	278	302	324
3/4	225	328	408	476	536	590	640	687
1	432	628	779	908	1,020	1,120	1,220	1,310
1 1/4	901	1,310	1,620	1,890	2,120	2,330	2,530	2,710
1 1/2	1,360	1,970	2,440	2,840	3,190	3,510		
2	2,650	3,830	4,740	5,510	6,180	6,800		
2 1/2	4,260	6,140	7,580	8,810	9,890	10,900		
3	7,570	10,900	13,500	15,600	17,500	19,300		
4	15,500	22,300	27,600	32,000	35,900	39,400		
5	28,200	40,500	49,900	57,900	64,900	71,300		
6	45,800	65,600	80,900	93,800	105,000	115,000		

[a] Flow is in lb/h of 180°F water for Schedule 40 steel pipes.
[b] Flow calculated from Equation (1) and

Based on Darcey-Weisbach equation for fully flooded pipe

- Available head based on upstream pipe slope.
- Table has limited use. Only valid when pipe is 100% full. (inlet of traps or vented pipe below receiver.)

ASHRAE Table 36 for Wet (Fully Flooded) Returns

Table 36 Vented Wet Condensate Return for Gravity Flow Based on Darcy-Weisbach Equation

Nominal Diameter, in. IPS	Condensate Flow, lb/h[a,b]							
	Condensate Head, ft per 100 ft							
	0.5	1	1.5	2	2.5	3	3.5	4
1/2	105	154	192	224	252	278	302	324
3/4	225	328	408	476	536	590	640	687
1	432	628	779	908	1,020	1,120	1,220	1,310
1 1/4	901	1,310	1,620	1,890	2,120	2,330	2,530	2,710
1 1/2	1,360	1,970	2,440	2,840	3,190	3,510	3,800	4,080
2	2,650	3,830	4,740	5,510	6,180	6,800	7,360	7,890
2 1/2	4,260	6,140	7,580	8,810	9,890	10,900	11,800	12,600
3	7,570	10,900	13,500	15,600	17,500	19,300	20,900	22,300
4	15,500	22,300	27,600	32,000	35,900	39,400	42,600	45,600
5	28,200	40,500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	45,800	65,600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[a] Flow is in lb/h of 180°F water for Schedule 40 steel pipes.

- Based on 180°F water and Schedule 40 pipe.
- 212°F condensate is 2% lighter than 180°F condensate.
- Schedule 80 pipe has a smaller inside diameter.
- Assumes a safety factor of 3 or 33% pipe flow. 33% pipe flow maybe too conservative when pipe is 100% full.
- Be aware where safety factors are applied.

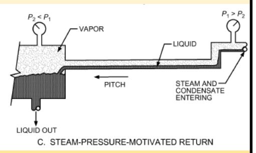
ASHRAE Table 37 for Non-Vented Dry Returns w/ Flash Steam

Table 37 Flow Rate for Dry-Closed Returns

Pipe Dia. D, in.	Supply Pressure = 5 psig Return Pressure = 0 psig			Supply Pressure = 15 psig Return Pressure = 0 psig			Supply Pressure = 30 psig Return Pressure = 0 psig			Supply Pressure = 50 psig Return Pressure = 0 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	240	520	1,100	95	210	450	60	130	274	42	92	200
3/4	510	1,120	2,400	210	450	950	130	280	590	91	200	420
1	1,000	2,150	4,540	400	860	1,820	250	530	1,120	180	380	800
1 1/4	2,100	4,500	9,500	840	1,800	3,800	520	1,110	2,340	370	800	1,680
1 1/2	3,170	6,780	14,200	1,270	2,720	5,700	780	1,670	3,510	560	1,200	2,520
2	6,240	13,300	*	2,500	5,320	*	1,540	3,270	*	1,110	2,350	*
2 1/2	10,000	21,300	*	4,030	8,520	*	2,480	5,250	*	1,780	3,780	*
3	18,000	38,000	*	7,200	15,200	*	4,440	9,360	*	3,190	6,730	*
4	37,200	78,000	*	14,900	31,300	*	9,180	19,200	*	6,660	13,800	*
6	110,500	*	*	44,300	*	*	27,300	*	*	19,600	*	*
8	228,600	*	*	91,700	*	*	56,400	*	*	40,500	*	*

Pipe Dia. D, in.	Supply Pressure = 100 psig Return Pressure = 0 psig			Supply Pressure = 150 psig Return Pressure = 0 psig			Supply Pressure = 100 psig Return Pressure = 15 psig			Supply Pressure = 150 psig Return Pressure = 15 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	28	62	133	23	51	109	56	120	260	43	93	200
3/4	62	134	290	50	110	230	120	260	560	93	200	420
1	120	260	544	100	210	450	240	500	1,060	180	390	800
1 1/4	250	540	1,130	200	440	930	500	1,060	2,200	380	800	1,680
1 1/2	380	810	1,700	310	660	1,400	750	1,600	3,320	570	1,210	2,500
2	750	1,590	*	610	1,300	*	1,470	3,100	6,450	1,120	2,350	4,900
2 1/2	1,200	2,550	*	980	2,100	*	2,370	5,000	10,300	1,800	3,780	7,800
3	2,160	4,550	*	1,760	3,710	*	4,230	8,860	*	3,200	6,710	*
4	4,460	9,340	*	3,640	7,630	*	8,730	18,200	*	6,620	13,800	*
6	13,200	*	*	10,800	*	*	25,900	53,600	*	19,600	40,600	*
8	27,400	*	*	22,400	*	*	53,400	110,300	*	40,500	83,600	*

*For these sizes and pressure losses, velocity is above 7000 fpm. Select another combination of size and pressure loss.



C. STEAM-PRESSURE-MOTIVATED RETURN

- Supply pressure = pressure at trap inlet.
- Return pressure = receiver pressure
- Psi/100 ft is based on gravity return pressure loss or pipe slope.
- Based on 180°F condensate, no safety factor, and schedule 40 pipe (assumed.)

ASHRAE Table 37 for Non-Vented Dry Returns w/ Flash Steam

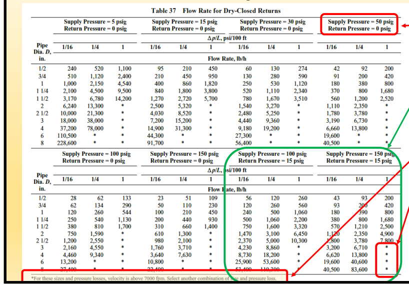


Table 37 Flow Rate for Dry-Closed Returns

Pipe Dia. D, in.	Supply Pressure = 5 psig Return Pressure = 0 psig			Supply Pressure = 15 psig Return Pressure = 0 psig			Supply Pressure = 30 psig Return Pressure = 0 psig			Supply Pressure = 50 psig Return Pressure = 0 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	240	520	1,100	95	210	450	60	130	274	42	92	200
3/4	510	1,120	2,400	210	450	950	130	280	590	91	200	420
1	1,000	2,150	4,540	400	860	1,820	250	530	1,120	180	380	800
1 1/4	2,100	4,500	9,500	840	1,800	3,800	520	1,110	2,340	370	800	1,680
1 1/2	3,170	6,780	14,200	1,270	2,720	5,700	780	1,670	3,510	560	1,200	2,520
2	6,240	13,300	*	2,500	5,320	*	1,540	3,270	*	1,110	2,350	*
2 1/2	10,000	21,300	*	4,030	8,520	*	2,480	5,250	*	1,780	3,780	*
3	18,000	38,000	*	7,200	15,200	*	4,440	9,360	*	3,190	6,730	*
4	37,200	78,000	*	14,900	31,300	*	9,180	19,200	*	6,660	13,800	*
6	110,500	*	*	44,300	*	*	27,300	*	*	19,600	*	*
8	228,600	*	*	91,700	*	*	56,400	*	*	40,500	*	*

Pipe Dia. D, in.	Supply Pressure = 100 psig Return Pressure = 0 psig			Supply Pressure = 150 psig Return Pressure = 0 psig			Supply Pressure = 100 psig Return Pressure = 15 psig			Supply Pressure = 150 psig Return Pressure = 15 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	28	62	133	23	51	109	56	120	260	43	93	200
3/4	62	134	290	50	110	230	120	260	560	93	200	420
1	120	260	544	100	210	450	240	500	1,060	180	390	800
1 1/4	250	540	1,130	200	440	930	500	1,060	2,200	380	800	1,680
1 1/2	380	810	1,700	310	660	1,400	750	1,600	3,320	570	1,210	2,500
2	750	1,590	*	610	1,300	*	1,470	3,100	6,450	1,120	2,350	4,900
2 1/2	1,200	2,550	*	980	2,100	*	2,370	5,000	10,300	1,800	3,780	7,800
3	2,160	4,550	*	1,760	3,710	*	4,230	8,860	*	3,200	6,710	*
4	4,460	9,340	*	3,640	7,630	*	8,730	18,200	*	6,620	13,800	*
6	13,200	*	*	10,800	*	*	25,900	53,600	*	19,600	40,600	*
8	27,400	*	*	22,400	*	*	53,400	110,300	*	40,500	83,600	*

*For these sizes and pressure losses, velocity is above 7000 fpm. Select another combination of size and pressure loss.

- Pressures determine amount of flash steam.
- Use last two tables when using flash tank vented to a 15 psig steam line.
- See note at bottom for starred values (*)
  - Steam velocities are limited to 7000 fpm
  - Use a different combination of pipe size and pressure loss.

ASHRAE Table 37 for Non-Vented Dry Returns w/ Flash Steam

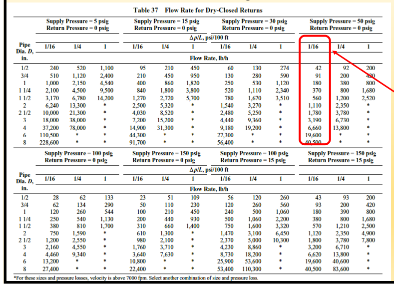


Table 37 Flow Rate for Dry-Closed Returns

Pipe Dia. D, in.	Supply Pressure = 5 psig Return Pressure = 0 psig			Supply Pressure = 15 psig Return Pressure = 0 psig			Supply Pressure = 30 psig Return Pressure = 0 psig			Supply Pressure = 50 psig Return Pressure = 0 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	240	520	1,100	95	210	450	60	130	274	42	92	200
3/4	510	1,120	2,400	210	450	950	130	280	590	91	200	420
1	1,000	2,150	4,540	400	860	1,820	250	530	1,120	180	380	800
1 1/4	2,100	4,500	9,500	840	1,800	3,800	520	1,110	2,340	370	800	1,680
1 1/2	3,170	6,780	14,200	1,270	2,720	5,700	780	1,670	3,510	560	1,200	2,520
2	6,240	13,300	*	2,500	5,320	*	1,540	3,270	*	1,110	2,350	*
2 1/2	10,000	21,300	*	4,030	8,520	*	2,480	5,250	*	1,780	3,780	*
3	18,000	38,000	*	7,200	15,200	*	4,440	9,360	*	3,190	6,730	*
4	37,200	78,000	*	14,900	31,300	*	9,180	19,200	*	6,660	13,800	*
6	110,500	*	*	44,300	*	*	27,300	*	*	19,600	*	*
8	228,600	*	*	91,700	*	*	56,400	*	*	40,500	*	*

Pipe Dia. D, in.	Supply Pressure = 100 psig Return Pressure = 0 psig			Supply Pressure = 150 psig Return Pressure = 0 psig			Supply Pressure = 100 psig Return Pressure = 15 psig			Supply Pressure = 150 psig Return Pressure = 15 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	28	62	133	23	51	109	56	120	260	43	93	200
3/4	62	134	290	50	110	230	120	260	560	93	200	420
1	120	260	544	100	210	450	240	500	1,060	180	390	800
1 1/4	250	540	1,130	200	440	930	500	1,060	2,200	380	800	1,680
1 1/2	380	810	1,700	310	660	1,400	750	1,600	3,320	570	1,210	2,500
2	750	1,590	*	610	1,300	*	1,470	3,100	6,450	1,120	2,350	4,900
2 1/2	1,200	2,550	*	980	2,100	*	2,370	5,000	10,300	1,800	3,780	7,800
3	2,160	4,550	*	1,760	3,710	*	4,230	8,860	*	3,200	6,710	*
4	4,460	9,340	*	3,640	7,630	*	8,730	18,200	*	6,620	13,800	*
6	13,200	*	*	10,800	*	*	25,900	53,600	*	19,600	40,600	*
8	27,400	*	*	22,400	*	*	53,400	110,300	*	40,500	83,600	*

*For these sizes and pressure losses, velocity is above 7000 fpm. Select another combination of size and pressure loss.

- Use 1/16” psi/100 ft when using pipe slopes less than 1 per 14 feet

Generating ASHRAE Table 37

Step 1 - Determine the maximum steam velocity for pressure drop rates consistent with pipe slope from ASHRAE Handbook of Fundamentals(2) Fig. 18 or other similar tables.

Step 1 – Use chart to determine steam velocities

(ASHRAE Figure 18 for Schedule 40 pipe shown)

$\Delta P = f \cdot L/D \cdot (V^2/2g)$

or

$V = (2g \cdot \Delta P/L \,/\, f \cdot D)^{1/2}$

Generating ASHRAE Table 37

Step 1 - Determine the maximum steam velocity for pressure drop rates consistent with pipe slope from ASHRAE Handbook of Fundamentals(2) Fig. 18 or other similar tables.

Step 2 - Determine the percent of flash steam based on the table supply and return pressures and equation 25 in Chapter 22 of the ASHRAE Handbook of Fundamentals(2).

Step 2 – Determine % Flash Steam

Given: Supply pressure = 15 psig
Return pressure = 0 psig
Atmospheric Pressure = 14.7 psia (round to 15 psia)

Steam Table Data:
Supply pressure = 30 psia, Saturated: Temp. = 250.3°F, h_f = 218.93 BTU/lb
Return pressure = 15 psia, Saturated: Temp. = 213.0°F, h_f = 181.21 BTU/lb, h_g = 1150.9 BTU/lb

X (% flash steam) = (218.93 – 181.21) / (1150.9-181.21) • 100% = 3.89%

Generating ASHRAE Table 37

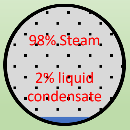
Step 1 - Determine the maximum steam velocity for pressure drop rates consistent with pipe slope from ASHRAE Handbook of Fundamentals(2) Fig. 18 or other similar tables.

Step 2 - Determine the percent of flash steam based on the table supply and return pressures and equation 25 in Chapter 22 of the ASHRAE Handbook of Fundamentals(2).

Step 3 - Determine the volume fraction of flash steam based on the table supply and return pressures and equation 26 in Chapter 22 of the ASHRAE Handbook of Fundamentals(2) or use the void fraction for the slip velocity method.

Flash Steam Volume per ASHRAE

2021 ASHRAE Handbook of Fundamentals, Chapter 22, equation 26

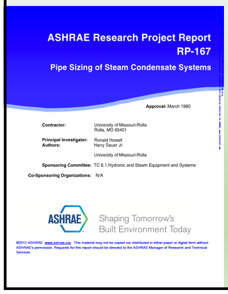


Volume fraction $V_c = x \cdot v_{g2} / (v_{f2} \cdot (1-x) + x \cdot v_{g2})$

Where
x = steam quality or percent steam
v_{f2}= specific volume of the liquid or 1/ density of liquid
v_{g2} = specific volume of flash steam

x (@15 psig) = 3.89%, v_{f2} = 0.016726 ft^3/lb_m , vg2 = 26.29 ft^3/lb_m
$V_c = 0.0389 \cdot 26.29 / (0.016726 \cdot (1-.0389) + 0.0389 \cdot 26.29)$ = 98.45% flash steam

ASHRAE Research Papers

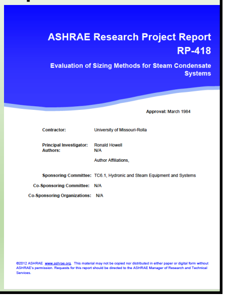

ASHRAE Research Project Report
RP-167
Pipe Sizing of Steam Condensate Systems

Approval: March 1980

Contractor: University of Missouri-Rolla
Rolla, MO 65401
Principal Investigator: Ronald Howell
Authors: Harry Sauer Jr.
University of Missouri-Rolla
Sponsoring Committee: TC 6.1,Hydronic and Steam Equipment and Systems
Co-Sponsoring Organizations: N/A

ASHRAE Shaping Tomorrow's Built Environment Today

- RP-167 Proposed the slip velocity concept.
- RP-418 Compared several alterative methods
- By Ronald Howell and Harry Sauer, 1980, 1984


ASHRAE Research Project Report
RP-418
Evaluation of Sizing Methods for Steam Condensate Systems

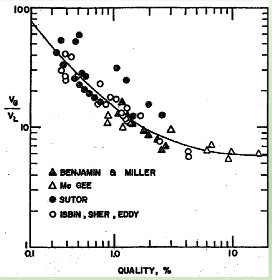
Approval: March 1984

Contractor: University of Missouri-Rolla
Principal Investigator: Ronald Howell
Authors: N/A
Author Affiliations,
Sponsoring Committee: TC6.1, Hydronic and Steam Equipment and Systems
Co-Sponsoring Committee: N/A
Co-Sponsoring Organizations: N/A

Two-Phase Steam Condensate Flow Characteristics

- Steam and liquid condensate have very different densities thus different friction rates when at the same velocity.
- Pressure drops are a function of velocity, density, and viscosity.
- Result is that steam and liquid condensate can be at different velocities when at the same pressure drop rate.
- Difference between steam and condensate velocities is called the 'slip velocity' or the amount of 'hold back'.
- ASHRAE equation 26 for volume fraction V_c does not apply.

Stratified Flow Two-Phase Velocity Ratio vs. Steam Quality, x%



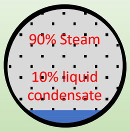
Experimental data chart from ASHRAE RP-167 for stratified flow regime.
Slip Velocity Ratio
$S = V_g / V_L = \exp[1.6677 - 0.0084 \cdot \ln(x)^3]$

Void fraction = α_g =
$1/(S \cdot v_f / v_g \cdot (1-x)/x+1)$

Where
V_g = velocity of vapor
V_L = velocity of liquid
v_f= specific volume of liquid (1/density)
v_g= specific volume of vapor
x = steam quality or percent steam

Flash Steam Volume per Slip Velocity Method

Slip Velocity Ratio @ 15 psig
$S = V_g / V_L = \exp[1.6677 - 0.0084 \cdot \ln(x)^3]$
$S = \exp[1.6677 - 0.0084 \cdot \ln(0.0389)^3] = 7.07$
(steam moves 7 x faster than liquid condensate)



Void Fraction @ 15 psig
$\alpha_g = 1/(S \cdot \rho_g / \rho_f \cdot (1-x)/x+1)$ =
$\alpha_g = 1/(7.07 \cdot 0.0167261 / 26.29 \cdot (1-0.0389)/0.0389+1) = 90.0\%$

8.6% less than the volume fraction of 98.45% at 15 psig.
Even greater difference when using supply pressures less than 15 psig.
Note: Void fraction = volume fraction when S = 1.0

Generating ASHRAE Table 37

Step 4 - Determine the flash steam flow based on the maximum velocity in step 1 and the steam flow area based on actual inside pipe diameter, and steam volume/void fraction in step 3.

Pipe Area Adjustments

		SCHEDULE 40 PIPE			Schedule 80			
Nominal Size (in.)	STD CS Pipe OD (in.)	Wall Thick. (in.)	Inside Diameter (in.)	Flow Area (sf)	Wall Thick. (in.)	Inside Diameter (in.)	Flow Area (sf)	% Change
0.5	0.84	0.109	0.622	0.002109	0.147	0.546	0.001625	-22.9
0.75	1.05	0.113	0.824	0.003701	0.154	0.742	0.003001	-18.9
1	1.315	0.133	1.049	0.005999	0.179	0.957	0.004993	-16.8
1.25	1.66	0.140	1.38	0.010382	0.191	1.278	0.008904	-14.2
1.5	1.9	0.145	1.61	0.014131	0.200	1.5	0.012266	-13.2
2	2.375	0.154	2.067	0.023291	0.218	1.939	0.020496	-12.0
2.5	2.875	0.203	2.469	0.033231	0.276	2.323	0.029417	-11.5
3	3.5	0.216	3.068	0.051312	0.300	2.9	0.045846	-10.7
4	4.5	0.237	4.026	0.088360	0.337	3.826	0.079799	-9.7
6	6.625	0.280	6.065	0.200525	0.432	5.761	0.180927	-9.8
8	8.625	0.322	7.981	0.347234	0.500	7.625	0.316947	-8.7

Schedule 80 has 9 to 23% less flow area than Schedule 40.

Steam Velocity Adjustments

Nominal Size (in.)	Sch 40 Inside Diameter (in.)	1/16 psi/100' Flash Steam Velocity (fpm)	Sch 80 Inside Diameter (in.)	1/16 psi/100' Flash Steam Velocity (fpm)
0.5	0.622	879	0.546	807
0.75	0.824	1,056	0.742	986
1	1.049	1,235	0.957	1,164
1.25	1.38	1,473	1.278	1,402
1.5	1.61	1,625	1.5	1,553
2	2.067	1,904	1.939	1,828
2.5	2.469	2,130	2.323	2,050
3	3.068	2,441	2.9	2,356
4	4.026	2,891	3.826	2,801
6	6.065	3,725	5.761	3,609
8	7.981	4,409	7.625	4,287

$\Delta P = f \cdot L/D \cdot (V^2/2g)$

or

$V = (2g \cdot \Delta P/L / f \cdot D)^{1/2}$

Note that the friction factor f also changes with Reynolds Number and pipe diameter.
Schedule 80 has lower velocities.

Step 4 – Determine Flash Steam Flow

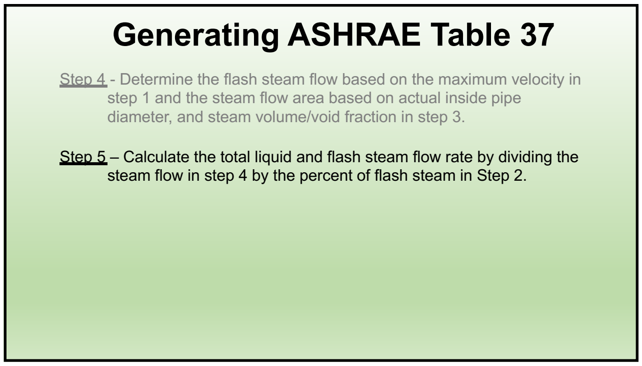
Steam flow = A • V • ρ

Or

Flow (PPH) = pipe area (ft^2) • flow fraction • velocity (ft/min) • 60 min/hr • lbs/ft^3

15 psig supply, 0 psig return

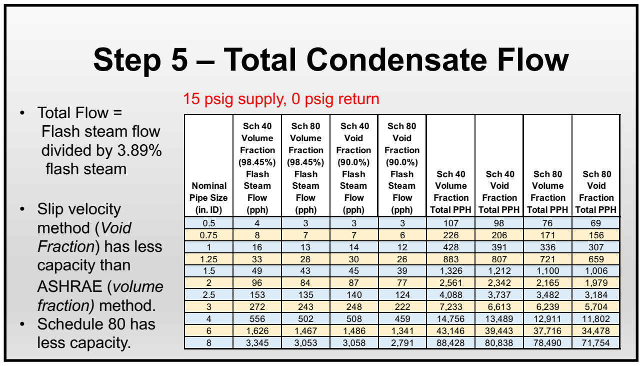
Nominal Pipe Size (in. ID)	Sch 40 Flow Area (sf)	1/16 psi/100' Flash Steam Velocity (fpm)	Sch 80 Flow Area (sf)	1/16 psi/100' Flash Steam Velocity (fpm)	Sch 40 Volume Fraction (98.45%) Flash Steam Flow (pph)	Sch 80 Volume Fraction (98.45%) Flash Steam Flow (pph)	Sch 40 Void Fraction (90.0%) Flash Steam Flow (pph)	Sch 80 Void Fraction (90.0%) Flash Steam Flow (pph)
0.5	0.002109	879	0.001625	807	4	3	4	3
0.75	0.003701	1,056	0.003001	986	9	7	8	6
1	0.005999	1,235	0.004993	1,164	17	13	15	12
1.25	0.010382	1,473	0.008904	1,402	34	28	31	26
1.5	0.014131	1,625	0.012266	1,553	52	43	47	39
2	0.023291	1,904	0.020496	1,828	100	84	91	77
2.5	0.033231	2,130	0.029417	2,050	159	135	145	124
3	0.051312	2,441	0.045846	2,356	281	243	257	222
4	0.088360	2,891	0.079799	2,801	574	502	525	459
6	0.200525	3,725	0.180927	3,609	1,678	1,467	1,534	1,341
8	0.347234	4,409	0.316947	4,287	3,440	3,053	3,145	2,791



Generating ASHRAE Table 37

Step 4 - Determine the flash steam flow based on the maximum velocity in step 1 and the steam flow area based on actual inside pipe diameter, and steam volume/void fraction in step 3.

Step 5 – Calculate the total liquid and flash steam flow rate by dividing the steam flow in step 4 by the percent of flash steam in Step 2.

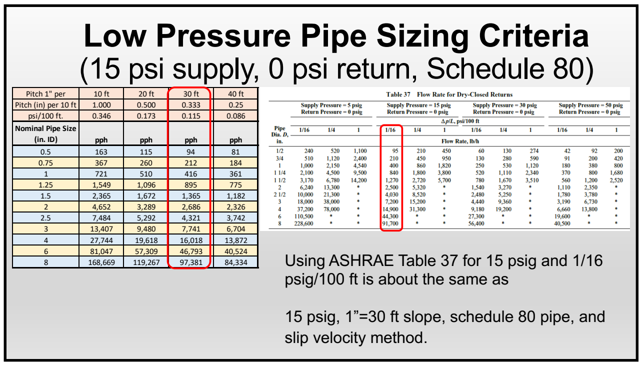


Step 5 – Total Condensate Flow

- Total Flow =
  Flash steam flow divided by 3.89% flash steam
- Slip velocity method (*Void Fraction*) has less capacity than ASHRAE (*volume fraction)* method.
- Schedule 80 has less capacity.

15 psig supply, 0 psig return

Nominal Pipe Size (in. ID)	Sch 40 Volume Fraction (98.45%) Flash Steam Flow (pph)	Sch 80 Volume Fraction (98.45%) Flash Steam Flow (pph)	Sch 40 Void Fraction (90.0%) Flash Steam Flow (pph)	Sch 80 Void Fraction (90.0%) Flash Steam Flow (pph)	Sch 40 Volume Fraction Total PPH	Sch 40 Void Fraction Total PPH	Sch 80 Volume Fraction Total PPH	Sch 80 Void Fraction Total PPH
0.5	4	3	3	3	107	98	76	69
0.75	8	7	7	6	226	206	171	156
1	16	13	14	12	428	391	336	307
1.25	33	28	30	26	883	807	721	659
1.5	49	43	45	39	1,326	1,212	1,100	1,006
2	96	84	87	77	2,561	2,342	2,165	1,979
2.5	153	135	140	124	4,088	3,737	3,482	3,184
3	272	243	248	222	7,233	6,613	6,239	5,704
4	556	502	508	459	14,756	13,489	12,911	11,802
6	1,626	1,467	1,486	1,341	43,146	39,443	37,716	34,478
8	3,345	3,053	3,058	2,791	88,428	80,838	78,490	71,754



Low Pressure Pipe Sizing Criteria

(15 psi supply, 0 psi return, Schedule 80)

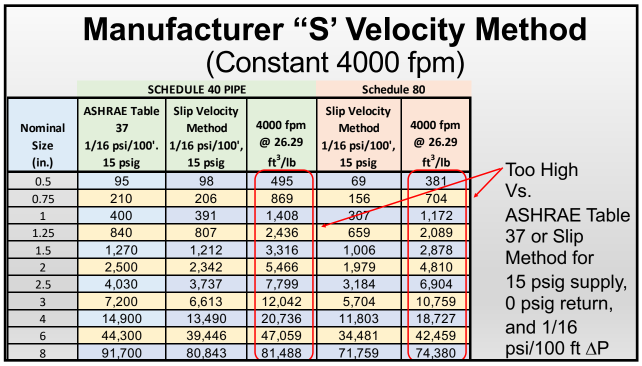
Pitch 1" per	10 ft	20 ft	30 ft	40 ft
Pitch (in) per 10 ft	1.000	0.500	0.333	0.25
psi/100 ft.	0.346	0.173	0.115	0.086
Nominal Pipe Size (in. ID)	**pph**	**pph**	**pph**	**pph**
0.5	163	115	94	81
0.75	367	260	212	184
1	721	510	416	361
1.25	1,549	1,096	895	775
1.5	2,365	1,672	1,365	1,182
2	4,652	3,289	2,686	2,326
2.5	7,484	5,292	4,321	3,742
3	13,407	9,480	7,741	6,704
4	27,744	19,618	16,018	13,872
6	81,047	57,309	46,793	40,524
8	168,669	119,267	97,381	84,334

Table 37 Flow Rate for Dry-Closed Returns

Pipe Dia. *D*, in.	Supply Pressure = 5 psig Return Pressure = 0 psig			Supply Pressure = 15 psig Return Pressure = 0 psig			Supply Pressure = 30 psig Return Pressure = 0 psig			Supply Pressure = 50 psig Return Pressure = 0 psig		
	Δ*p*/*L*, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
	Flow Rate, lb/h											
1/2	240	520	1,100	95	210	450	60	130	274	42	92	200
3/4	510	1,120	2,400	210	450	950	130	280	590	91	200	420
1	1,000	2,150	4,540	400	860	1,820	250	530	1,120	180	380	800
1 1/4	2,100	4,500	9,500	840	1,800	3,800	520	1,110	2,340	370	800	1,680
1 1/2	3,170	6,780	14,200	1,270	2,720	5,700	780	1,670	3,510	560	1,200	2,520
2	6,240	13,300	*	2,500	5,320	*	1,540	3,270	*	1,110	2,350	*
2 1/2	10,000	21,300	*	4,030	8,520	*	2,480	5,250	*	1,780	3,780	*
3	18,000	38,000	*	7,200	15,200	*	4,440	9,360	*	3,190	6,730	*
4	37,200	78,000	*	14,900	31,300	*	9,180	19,200	*	6,660	13,800	*
6	110,500	*	*	44,300	*	*	27,300	*	*	19,600	*	*
8	228,600	*	*	91,700	*	*	56,400	*	*	40,500	*	*

Using ASHRAE Table 37 for 15 psig and 1/16 psig/100 ft is about the same as

15 psig, 1”=30 ft slope, schedule 80 pipe, and slip velocity method.

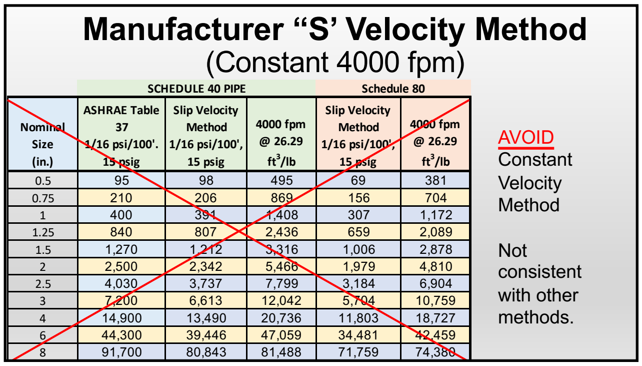


Manufacturer “S’ Velocity Method

(Constant 4000 fpm)

	SCHEDULE 40 PIPE			Schedule 80	
Nominal Size (in.)	**ASHRAE Table 37 1/16 psi/100'. 15 psig**	**Slip Velocity Method 1/16 psi/100', 15 psig**	**4000 fpm @ 26.29 ft^3/lb**	**Slip Velocity Method 1/16 psi/100', 15 psig**	**4000 fpm @ 26.29 ft^3/lb**
0.5	95	98	495	69	381
0.75	210	206	869	156	704
1	400	391	1,408	307	1,172
1.25	840	807	2,436	659	2,089
1.5	1,270	1,212	3,316	1,006	2,878
2	2,500	2,342	5,466	1,979	4,810
2.5	4,030	3,737	7,799	3,184	6,904
3	7,200	6,613	12,042	5,704	10,759
4	14,900	13,490	20,736	11,803	18,727
6	44,300	39,446	47,059	34,481	42,459
8	91,700	80,843	81,488	71,759	74,380

Too High Vs. ASHRAE Table 37 or Slip Method for 15 psig supply, 0 psig return, and 1/16 psi/100 ft ΔP



Manufacturer “S’ Velocity Method

(Constant 4000 fpm)

	SCHEDULE 40 PIPE			Schedule 80	
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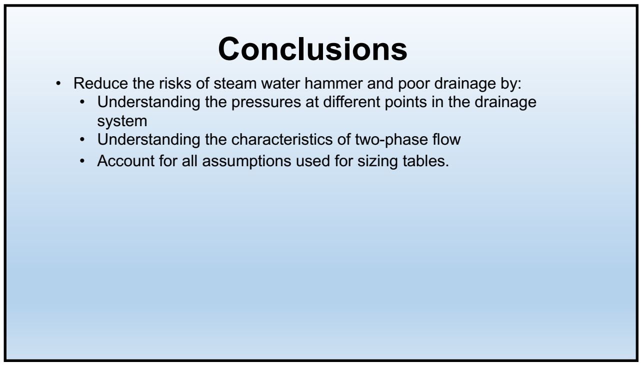
AVOID Constant Velocity Method

Not consistent with other methods.



Conclusions

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Conclusions

- Reduce the risks of steam water hammer and poor drainage by:
  - Understanding the pressures at different points in the drainage system
  - Understanding the characteristics of two-phase flow
  - Account for all assumptions used for sizing tables.
- Use pressure drop rates consistent with actual pipe slopes.
- Be aware of assumptions for ASHRAE tables.

  ASHRAE tables could be improved by:
  - Providing more useful information
  - Stating all assumptions and safety factors
  - Updating Table 37 for slip velocity method as described in ASHRAE RP-167
  - Providing tables for both Schedule 40 and Schedule 80 pipe.

Questions?

gcnelson65@gmail.com