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Condensate Line Sizing for Gravity Returns from Steam Traps and Heat Recovery

With efficient energy use being important to all users of steam, maximizing the recovery of heat is of utmost importance. In the past, energy costs were low, water resources were plentiful, and carbon emissions had not yet become an issue. These economic and environmental aspects made dumping condensate an acceptable practice. Now, with present-day conditions, dumping condensate is a far less justifiable option.

Most cities implement a maximum allowable effluent temperature (typically 140°F). As such, condensate cannot be dumped directly into sewer lines. This maximum condensate temperature ensures that any water reaching the sewer treatment plant will not kill bacteria beds that are necessary for the treatment process. Therefore, in order to dump hot condensate, cooling water must be added until the temperature is below the maximum allowed by the public sewage authorities. This cooling process can be costly and impractical, particularly if direct water injection is used.

In some cases, where there is no condensate return capability (such as with district steam systems or where contamination may be an issue), heat exchangers or condensate coolers can be used to recover heat from the condensate and flash steam to maximize energy efficiency. High pressure condensate’s flash steam can also be recovered and supplied to a lower pressure steam system. Such flash recovery is accomplished by using a flash vessel and associated controls to separate condensate and flash steam, diverting the flash steam into a lower pressure steam header or usage point. In some cases, condensate collected from a high pressure steam main is discharged into the low pressure steam main, but this practice is not recommended as it increases the condensate load in the lower pressure system. Such cascading of condensate into a low pressure steam system increases liquid mass which can increase difficulties of a water hammer condition, while simultaneously increasing the recipient steam’s wetness.

Two main considerations of sizing condensate lines are to reduce backpressure and line velocity for several reasons, including to avoid water hammer and high system back pressure that restricts production capability. Furthermore, it is recommended that consistent checking of each steam trap’s condition is sustained with appropriate maintenance action of faulty traps to prevent condensate return line over pressurization from leaking steam. Excess steam in the condensate header also increases the chances of steam pocket collapse, which can lead to steam-induced water hammer conditions.

Condensate Return Line Sizing

Condensate lines from steam trap discharges have to carry both liquid and flash steam together through the piping. Proper sizing of the condensate return lines is important to ensure the safe and reliable transfer of this two-phase flow to the recovery system. The pipe on the discharge side of the steam trap should never be smaller than the outlet connection on the trap.

Additionally, the size of the condensate return line should generally be larger than the steam trap discharge pipe. In a gravity return, the condensate will run along the bottom of the piping while the flash steam travels above. It is important that the speed of the flowing mixture not be excessive. Excessive velocity in the return line can allow for water hammer due to slugs of liquid being pushed along the piping system.

To size the condensate return line properly, you will need to know the following information:

- Steam pressure at steam trap inlet
- Amount of condensate #/hr.
- Pressure in the condensate return line (is the condensate going to a vented receiver, a pressurized flash tank, or a DA tank).
- Sensible heat of condensate at the steam trap inlet (See Table 1-1 based on the steam trap inlet pressure)
- Sensible heat of condensate return flow (see Table 1-1 for sensible heat based upon operating pressure of the condensate return line)
- Specific volume of flash steam flowing in the condensate return line (see steam table for specific volume of flash steam)
- Flash steam velocity 3,000 to 4,000 ft/min maximum

Glossary of terms:

L= latent heat BTU/lb (see Table 1.1, saturated steam latent heat value, adjust for wetness percent)

Q= condensate generated, lb/hr.

Qi = Incoming condensate flow, lb/hr.

S= sensible heat in BTU/lb.

Sh = sensible heat, higher pressure (BTU/lb)

Sl = sensible heat, lower pressure (BTU/lb)

Ll = latent heat of lower pressure (BTU/lb)

FS = flash steam (lb/hr)

Q = condensate generated (lb/hr)

Sv = specific volume of steam (cu ft/lb)

Pa = pipe area required (sq inches)

Svel = steam velocity (ft/min)

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Formulas:

Note: For any formula requiring latent heat (L, Ll, or sensible heat (S, Sh, Sl) use Table 1-1.

To calculate amount of flash steam % use the following formula:

(Sh – Sl) / Ll= flash steam %

Example: 100 psig condensate flowing through steam trap to a 0 psig gravity return

Sh of 100 psig condensate = 309 btu/lb
Sl of 0 psig condensate = 180 btu/lb
Ll of 0 psig condensate = 970 btu/lb

Flash steam % = (309-180) / 970 = 0.133 or 13.3%

To determine the amount of flash steam (lb/hr) using following formula:

FS= Q X FS% = total flash steam

Formula to calculate required pipe area:

Pa = (((2.4 X FS X Sv) / Svel) = area required for flash steam

((Q- FS) X 0.016) / (FS*Sv) = % of pipe area in square inches for condensate

(Pa for flash flow) x (1 + % of pipe area) = total pipe required

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Example 1: 100 psig condensate flowing through steam trap at 5,000 lb/hr to a 0 psig gravity return, schedule 40 pipe

Fs= 5,000 X 0.132 = 660 lb/hr

Condensate flow = 5,000 lb/hr - 660 lb/hr = 4340 lb/hr condensate in 0 psig gravity return

Pa = (2.4 X 660 X 26.8) / 3,000 = 14.15 sq. inch. area required for flash steam

(5000-660) X 0.0160 / (660 X 26.8) = 0.0039 or 0.39% of pipe area for condensate

Total pipe required = 14.15 x (1 + 0.0039) = 14.2 sq inch

To choose required pipe size see table 1-2

The required need for a 14.2 sq inch internal pipe area would require a 5” (realistically a 6”) schedule 40 pipe to maintain a flow velocity below 3000 Ft/min.

Alternatively, using the Pa formula to solve for Svel if using a 4” schedule 40 pipe with internal area of 12.73 Sq. In.;

12.73 / (1 + 0.0039) = 12.68 sq inch

Svel (4”) = (2.4 X 660 X 26.8) / 12.68) = 3,348 ft/min

Example 2: 200 psig condensate flowing through steam trap at 15,000 lb/hr to a 30 psig flash tank, gravity return, schedule 80 pipe

Flash steam % = (362 - 243) / 929 = 0.128 or 12.8%

Fs = 15,000 X 0.128 = 1920 lb/hr

Condensate flow = 15,000 lb/hr - 1920 lb/hr = 13,080 lb/hr condensate in 30 psig gravity return

Pa = (2.4 X 1920 X 26.8) / 3000 = 41.16 sq inch for flash steam

(15000-1920) X 0.0160 / (660 X 26.8) = 0.012 or 1.2% of pipe area for condensate

Total pipe required = 41.16 x (1 + 0.012) = 41.65 sq inch

To choose required pipe size see table 1-2

The required need for a 41.65 sq inch internal pipe area would require an 8” schedule 80 pipe to maintain a flow velocity below 3000 Ft/min.

Example 3: Multiple condensate sources flowing to a 5 psig DA tank schedule 80 pipe

A. 200 psig 5,000 lb/hr
B. 150 psig 7,500 lb/hr
C. 50 psig 10,000 lb/hr

Flash steam % @ 200 psig= (362 - 195) / 960 = 0.174 or 17.4%

Fs @ 200 psig = 5,000 X 0.174 = 870 lb/hr

Flash steam % @ 150 psig= (339 - 195) / 960 = 0.15 or 15.0%

Fs @ 150 psig = 7,500 X .15 = 1,125 lb/hr

Flash steam % @ 50 psig = (267 - 195) / 960 = 0.075 or 7.5%

Fs @ 50 psig = 10,000 X .075 = 750 lb/hr

Total flash steam = 870 + 1,125 + 750 = 2,745 lb/hr.

Total condensate flow from traps = 5,000 + 7,500 + 10,000 = 22,500 lb/h.

Condensate flow = 22,500 lb/hr - 2745 lb/hr = 19,755 lb/hr condensate in 5 psig gravity return

Pa = (2.4 X 2,745 X 20.17) / 3000 = 44.29 sq inch for flash steam

(22,500-2745) X 0.0160 / (2745 X 20.17) = 0.0057 or 0.57% of pipe area for condensate

Total pipe required = 44.29 x (1 + 0.0042) = 44.54 sq inch

To choose required pipe size see table 1-2

The required need for a 44.54 sq inch internal pipe area would require an 8" schedule 80 pipe to maintain a flow velocity below 3000 Ft/min.

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Table 1-1 Latent Heat and Sensible Heat at Various Saturated Steam Pressures

Pressure (psig)	Latent heat Btu/lb	Sensible heat Btu/lb	*Specific volume cu.ft./lb*	Pressure (psig)	Latent heat Btu/lb	Sensible heat Btu/#	Specific volume cu.ft./lb	Pressure (psig)	Latent heat Btu/ #	Sensible heat Btu/#	Specific volume cu.ft./lb
0	970	180	*26.8*	**105**	878	312	3.74	**310**	802	402	1.43
1	968	183	*25.2*	**110**	875	316	3.59	**315**	800	404	1.41
2	966	187	*23.5*	**115**	873	319	3.46	**320**	799	405	1.38
3	964	190	*22.3*	**120**	871	322	3.34	**325**	797	407	1.36
4	962	192	*21.4*	**125**	868	325	3.23	**330**	796	408	1.34
5	960	195	*20.1*	**130**	866	328	3.12	**335**	794	410	1.33
6	959	198	*19.4*	**135**	864	330	3.02	**340**	793	411	1.31
7	957	200	*18.7*	**140**	861	333	2.92	**345**	791	413	1.29
8	956	201	*18.4*	**145**	859	336	2.84	**350**	790	414	1.28
9	954	205	*17.1*	**150**	857	339	2.74	**355**	789	416	1.26
10	953	207	*16.5*	**155**	855	341	2.68	**360**	788	417	1.24
12	949	212	*15.3*	**160**	853	344	2.60	**365**	786	419	1.22
14	947	216	*14.3*	**165**	851	346	2.54	**370**	785	420	1.20
16	944	220	*13.4*	**170**	849	348	2.47	**375**	784	421	1.19
18	941	224	*12.6*	**175**	847	351	2.41	**380**	783	422	1.18
20	939	227	*11.9*	**180**	845	353	2.34	**385**	781	424	1.16
22	937	230	*11.3*	**185**	843	355	2.29	**390**	780	425	1.14
24	934	233	*10.8*	**190**	841	358	2.24	**395**	778	427	1.13
26	933	236	*10.3*	**195**	839	360	2.19	**400**	777	428	1.12
28	930	239	*9.85*	**200**	837	362	2.14	**450**	766	439	1.00
30	929	243	*9.46*	**205**	836	364	2.09	**500**	751	453	.89
32	927	246	*9.10*	**210**	834	366	2.05	**550**	740	464	.82
34	925	248	*8.75*	**215**	832	368	2.00	**600**	730	473	.75
36	923	251	*8.42*	**220**	830	370	1.96	**650**	719	483	.69
38	922	253	*8.08*	**225**	828	372	1.92	**700**	710	491	.64
40	920	256	*7.82*	**230**	827	374	1.89	**750**	696	504	.60
42	918	258	*7.57*	**235**	825	376	1.85	**800**	686	512	.56
44	917	260	*7.31*	**240**	823	378	1.81	**900**	666	529	.49
46	915	262	*7.14*	**245**	822	380	1.78	**1000**	647	544	.44
48	914	264	*6.94*	**250**	820	382	1.75	**1250**	600	580	.34
50	912	267	*6.68*	**255**	819	383	1.72	**1500**	557	610	.23
55	909	271	*6.27*	**260**	817	385	1.69	**1750**	509	642	.22
60	906	277	*5.84*	**265**	815	387	1.66	**2000**	462	672	.19
65	901	282	*5.49*	**270**	814	389	1.63	**2250**	413	701	.16
70	898	286	*5.18*	**275**	812	391	1.60	**2500**	358	733	.13
75	895	290	*4.91*	**280**	811	392	1.57	**2750**	295	764	.11

80	891	294	*4.67*	**285**	809	394	1.55	**3000**	213	804	.08
85	889	298	*4.44*	**290**	808	395	1.53				
90	886	302	*4.24*	**295**	806	397	1.49				
95	883	305	*4.05*	**300**	805	398	1.47				
100	880	309	*3.89*	**305**	803	400	1.45				

Table 1-2 - Internal Square Inches of Schedule 40 and Schedule Steel Pipe

Pipe size (inches)	Schedule 40 pipe internal Sq. In.	Schedule 80 pipe internal Sq. In.
½	.304	.234
¾	.533	.433
1	.864	.719
1-1/4	1.495	1.283
1-1/2	2.036	1.767
2	3.355	2.953
2-1/2	4.788	4.238
3	7.393	6.605
4	12.73	11.497
5	20.00	18.194
6	28.89	26.067
8	50.02	45.663
10	78.85	71.84
12	111.9	101.64
14	135.3	122.72
16	176.7	160.92
18	224.0	204.24
20	278.0	252.72
24	402.1	365.22