Injector Tests

by

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AT

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THESIS

The object of this thesis, is, to determine the effect of the temperature of feed water upon the amount of water delivered, by an injector on a three foot lift, per pound of steam.

The injector used was a Penberthy Auto-Position Injector; catalog No. 117. It was connected up as shown in sketch. The injector, all steam pipes and the calorimeter were wound with hair felt to prevent condensation by radiation.

As feed and delivery tanks, we used two of the old boilers in the boiler house; numbered respectively No. 1 and No. 2 in sketch. They were calibrated to read to each cubic foot at 52°.5F. In calibrating tanks, a wooden frame supporting two glass tubes was attached to setting of boilers. The tubes were connected to boilers as shown in sketch. 62.4#, or one cu. ft. of water was then run into the boiler and the level of the water, as registered in glass, was marked off on scale side of the glass.

Both gauges and thermometers were calibrated before and after tests were run.

In mixing feed water so as to obtain the temperature desired for same; hot water was drawn from hot water tank into boiler No. 1, as shown in sketch. If necessary, enough cold water was added to bring temperature of feed water to temperature desired. The cold water connections were on the front of the boiler No. 1, and therefore not shown in sketch.

The method of running tests was as follows: The injector was started and the flow of feed water was regulated by valve A so that water in barrels maintained a constant level, giving a

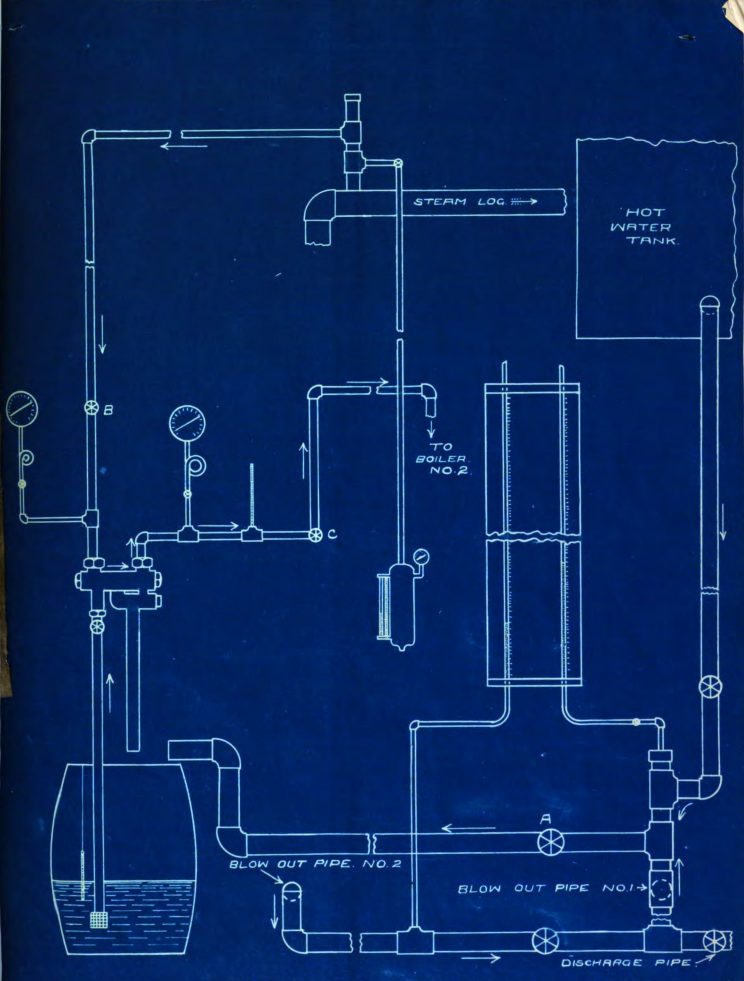
three foot lift. The steam and delivery pressures were throttled to 100# gauge by valves B and C respectively and the injector allowed to run a few minutes, until it became thoroughly heated up. At a given signal, valve A was closed and reading of two tanks taken when valve A was immediately opened again and regulated as before. The feed and delivery temperatures were also taken at this instant. The tests were continued for 45 minutes, temperatures of feed and delivery being taken every two and one half minutes. The steam and delivery pressures were kept constantly at 100# gauge throughout the test. At the end of forty-five minutes, readings of tanks were taken as at beginning. Thus it will be seen that a flying start and finish were made. The tests were all run with valve in suction pipe wide open.

The feed temperatures for tests were varied, as nearly as possible, by 10°F.

The temperature in the delivery tank was found to fall below that registered by thermometer in the delivery pipe, and in our computations has been used only to determine the actual number of pounds of water delivered by injector.

Calorimeter tests were run at the same time injector tests were run and the average quality of steam as found was used in computations.

All computations were made for one hour, as will be seen by observing equations in log of results.



SKETCH SHOWING METHOD OF CONNECTING INJECTOR AND THE ARRANGEMENT OF STEAM AND WATER PIPES.

Log of Results.

Time	Temp. Feed F°	Temp. Delivery F°
8:25	52.6	129.0
8:27.5	52.6	129.0
8:30	52.5	128.8
8:32.5	52.5	128.5
8:35	52.5	128.5
8:37.5	52.5	128.3
8:40	52.5	128.5
8:42.5	52.5	128.5
8:45	52.7	128.5
8:47.5	52.7	128.0
8:50	52.8	128.7
8:52.5	53.0	128.2
8:55	53.0	129.0
8:57.5	53.0	128.5
9:00	53.8	128.8
9:02.5	53.5	129.0
9:05	53.5	129.1
9:07.5	54.0	129.1
9:10	54.2	129.8
Average	52.9	128.9

	Reading of Tanks.	
Tank	Inital	Final
Feed	76.8 cu.ft.	11.5 cu. ft.
Delivery	9.6 cu. ft.	80.25 cu. ft.

Cu. ft. water supplied =65.3

Cu. ft. water delivered=70.65

Steam pressure=100#

Delivery pressure=100#

Calorimeter Readings.

No.	Steam Pressure	Steam Separated	Steam Run Through	% Steam
1	108	.075	3.08	97.1
2	111	.070	3.10	97.9

Average,--97.5

1. Duration of test = 45 minutes.

2. Steam pressure(p)=100#

3. Delivery pressure (P')=100#

4. Delivery head (H)=233.8 ft.

5. Suction head (H')=3 ft.

6. Temp. of supply (T)=52.9°F.

7. Temp. of delivery in tank (T')=117.6°F.

8. Lbs. of water supplied per hr.(W)=5433#

9. Lbs. of water delivered per hr.(W.)=5813.7#

10. Cu. ft. of water delivered per hr. (C)=94.2 cu. ft.

11. Wet steam delivered per hr.(W')=385.7#

12. Dry steam delivered per hr.(W'')=375.8#

13. Water delivered per lb. of wet steam=15.1#

14. Water delivered per lb. of dry steam=15.5#

15. Velocity of discharge in ft. per sec.

$$V=\frac{\text{(cu. ft. delivered) } 144}{3600\text{(area of discharge in sq. in.)}}=\frac{94.2 \times 144}{3600 \times .049}=76.9$$

16. Energy delivered raising injector water B.T.U. per hr.
N.B.— ± = plus.

$$\frac{W(H \pm H')}{778} \pm W'H = \frac{5433 \times 236.8 \pm 385.7 \times 233.8}{778} = 1771 \text{ B.T.U.}$$

17. Energy delivered heating injector water B.T.U. per hr.

$W(Q'-Q)=5433(97-21)=402908$ B.T.U.

18. Energy delivered velocity of discharge B.T.U. per hr.

$$\frac{W.V}{2g \times 778}=\frac{5818.7 \times (76.9)^2}{64.4 \times 778}= 695 \text{ B. T. U.}$$

19. Total energy delivered =(16) ± (17) ± (18) ± $W'q_t$ =

1771 ± 402908 ± 695 ± 385.7 x 97=442786.9 B.T.U.

20. Energy supplied=W'(xr ± q)=385.7(.975 x 876.5 ± 308.5)=443607.7 BT.U.

21. Efficiency=$\frac{442786.9}{443607.7}$ = 99%

Log of Results.

Time	Temp. Feed F°	Temp. Delivery F°
11:45	61.5	137.8
11:47.5	61.0	137.0
11:50	60.7	136.6
11:52.5	60.9	136.9
11:55	61.0	136.0
11:57.5	61.0	136.8
12:00	61.0	136.9
12:02.5	61.0	136.9
12:05	61.1	137.0
12:07.5	61.3	136.9
12:10	61.4	136.7
12:12.5	61.5	137.1
12:15	61.5	137.2
12:17.5	61.6	137.5
12:20	61.7	137.8
12:22.5	61.9	137.7
12:25	62.0	137.8
12:27.5	62.2	138.0
12:30	62.4	138.1
Average	61.4	137.2

Reading of Tanks.

Tank	Inital	Final
Feed	79.3	15.8
Delivery	8.5	77.6

Cu. ft. of water supplied=63.5

Cu. ft. of water delivered=69.1

Steam pressure=100#

Delivery pressure=100#

Calorimeter Readings.

No.	Steam Pressure	Water Separated #	Steam Run Through #	% Steam
1	112	.070	3.12	97.8
2	110	.075	2.98	97.6
3	110	.060	2.98	97.5
			Average,----	97.6

1. Duration of test =45 minutes.

2. Steam pressure(P)=100#

3. Delivery pressure =100#

4. Delivery head (H)= 234 feet.

5. Suction head (H')=3 feet.

6. Temp. of supply (T)=61.4°F.

7. Temp. in delivery tank(T')=127°F.

8. Lbs. of water supplied per hr.(W)=5274.2

9. Lbs. of water delivered per hr.(W')=5663.1

10. Cu. ft. delivered per hr.(C)=92.

11. Wet steam delivered per hr.(W')=393.9#

12. Dry steam delivered per hr.(W")=384.4#

13. Water delivered per lb. wet steam=14.5#

14. Water delivered per lb. dry steam =14.9#

15. Velocity of discharge in feet per sec.

$$V = \frac{\text{(cu. ft. delivery)} \times 144}{3600 \times \text{(area discharge in sq. ft.)}} = \frac{92 \times 144}{3600 \times .049} = 75.1$$

16. Energy delivered raising injector water B.T.U. per hr.

$$\frac{W(H + H')}{778} + W'H' = \frac{5274.2\ (234 + 3)}{778} + 393.9 \times 234 = 1725.1$$

17. Energy delivered heating injector water B.T.U per hr.

$W(Q-Q')=5274.2(105.2-29.4)=420881.1$

18. Energy delivered velocity of discharge B.T.U. per hr.

$$\frac{W.V^2}{29 \times 778} = \frac{5663.1 \times (75.1)^2}{64.4 \times 778} = 650.$$

19. Total energy delivered =(16) + (17) + (18) + $W'q_t$ =

1725.1 + 420881.1 + 650 + 393.9 x 105.2 = 464681.5 B.T.U.

20. Energy supplied per hr. = W'(xr + q) =

393.9 (.976 x 876.5 + 306.5)=468499.6 B.T.U.

21. Efficiency = $\frac{464681.5}{468499.6}$ =99.1%

Log of Results.

Time	Feed Temp. F°	Delivery Temp. F°
9:55	72.5	149.9
9:57.5	72.5	149.7
10:00	72.6	150.0
10:02.5	72.8	150.0
10:05	73.0	150.2
10:07.5	73.1	150.2
10:10	73.5	149.9
10:12.5	73.5	150.2
10:15	73.6	150.1
10:17.5	74.0	151.0
10:20	74.0	150.8
10:22.5	74.1	151.0
10:25	74.2	151.8
10:27.5	74.4	151.8
10:30	74.5	151.0
10:32.5	74.7	151.9
10:35	75.0	151.9
10:37.5	75.1	152.1
10:40	75.5	152.0
Average	73.9	150.9

Reading of Tanks.

Tank	Inital	Final
Feed	70.5	9.9
Delivery	8.4	74.7

Cu. ft. of water supplied =60.6

Cu. ft. of water delivered=66.3

Steam pressure =100#

Delivery pressure =100#

Calorimiter Readings.

No.	Steam Pressure	Water Separated #	Steam Run Through	% Steam
1	114	.03	3.16	97.8
2	114	.07	3.16	97.6
3	113	.07	3.14	97.5
			Average,--	97.63

1. Duration of test =45 minutes.

2. Steam pressure (P)=100#

3. Delivery pressure (P')=100#

4. Delivery head (H) =235.8 ft.

5. Suction head (H')=3 ft.

6. Temp. of supply (T)=73.9°F.

7. Temp. of delivery in tank (T')=142.1°F.

8. Lbs. of water supplied per hr.(W)=5042#

9. Lbs. of water delivered per hr.(W.)=5422.4#

10. Cu. ft. of water delivered per hr.(C)=88.4

11. Wet steam delivered per hr. (W')=380.4#

12. Dry steam delivered per hr. (W")=371.9#

13. Water delivered per lb. of wet steam =14.3#

14. Water delivered per lb. of dry steam =14.7#

15. Velocity of discharge in ft. per sec.=

$$V=\frac{\text{(cu. ft. delivered per hr.)} \times 144}{3600(\text{area of discharge II"})} = \frac{88.4 \times 144}{3600 \times .049} = 72.2$$

16. Energy delivered heating injector water B.T.U. per hr.

$$\frac{W(H \pm H')}{778} \pm W'H' = \frac{5042 \times (235.8 \pm 3)}{778} \pm \frac{380.4 \times 235.8}{778} = 1663$$

17. Energy delivered heating injector water B.T.U. per hr.

$W(Q'-Q)=5042(119-40.92)=393679.4$

18. Energy delivered velocity of discharge B.T.U. per hr.

$$\frac{W.v^2}{29 \times 778} = \frac{54224 \times (72.2)^2}{64.4 \times 778} = 564 \text{ B.T.U.}$$

19. Total energy delivered =(16) ± (17) ± (18) ± $W'q_t$
=1663 ± 393679 ± 564 ± 380.4 x 119 =440674 B.T.U.

20. Energy supplied =W'(xr±q)=380.4(.976 x 876.5 1 308.5)=442785.6B.T.

21. Efficiency = $\frac{440674}{442785.6}$ =99.7%

Time	Temp. Feed F°	Temp. Delivery F°.
1:25	80.5	156.0
1:27.5	80.0	157.0
1:30	79.6	157.5
1:32.5	79.5	157.0
1:35	79.6	157.5
1:37.5	80.0	157.5
1:40	80.0	158.0
1:42.5	80.5	158.4
1:45	80.5	158.0
1:47.5	80.7	158.0
1:50	81.0	158.8
1.52.5	81.1	158.9
1:55	81.3	158.9
1:57.5	81.5	158.8
2:00	81.6	159.0
2:02.5	82.0	159.4
2:05	82.0	159.2
2:07.5	82.2	159.0
2:10	82.4	159.0
Average	80.7	158.2

Reading of Tanks.

Tank	Inital	Final
Feed	76.9	16.9
Delivery	7.6	72.5

Cu. ft. of water supplied =60.0

Cu. ft. of water delivered =64.9

Steam pressure=100#

Delivery pressure =100#

Calorimeter Readings.

No.	Steam Pressure	Water Separated #	Steam Run Through #	% Steam
1	111	.070	3.10	97.8
2	110	.070	2.93	97.7
3	109	.065	2.96	97.9
			Average,------	97.75

1. Duration of test= 45 minutes.

2. Steam pressure (P)=100#

3. Delivery pressure (P')=100#

4. Delivery head (H)=235.3 ft.

5. Suction head (H')=5 ft.

6. Temp. of supply (T)=60°F.

7. Temp. of delivery in tank (T')=150°F.

8. Lbs. of water supplied per hr.(W)=4977.6#

9. Lbs. of water delivered per hr.(W.)=5557.4#

10. Cu. ft. of water delivered per hr.(C)=86.4 cu. ft.

11. Wet steam delivered per hr.(W')=379.8#

12. Dry steam delivered per hr.(W")=370.7#

13. Water delivered per lb. of wet steam=14.1#

14. Water delivered per lb. of dry steam =14.5#

15. Velocity of discharge in ft. per sec.=

$$V=\frac{\text{(cu. ft. delivered) } 144}{3600\text{(area of discharge in sq. in.)}}=\frac{86.4 \times 144}{3600 \times .049}=70.5$$

16. Energy delivered raising injector water B.T.U. per hr.

$$\frac{W(H+H')}{778}+W'H=\frac{4977.6 \times 238.3}{778}+379.8 \times 235.3=1639 \text{ B.T.U.}$$

17. Energy in heating injector water B.T.U. per hr.

$$W(Q'-Q)=4977.6(126.4-49.7)=381781.9 \text{ B.T.U.}$$

18. Energy delivered velocity of discharge B.T.U. per hr.

$$\frac{W.V^2}{2g \times 778}=\frac{5557.4 \times (70.5)}{64.4 \times 778}=551.4 \text{ B.T.U.}$$

19. Total energy delivered =(16) + (17) + (18) + $W'q_t$ =
1639 + 381781.9 + 551.4 + 379.8 x 126.4 =431959.2 B.T.U.

20. Energy supplied =W'(xr + q)=379.8 x 876.5 + 308.5)=442087.2 B.T.U.

21. Efficiency = $\frac{431959.2 \times 100}{442087.2}$=97.7%

Log of Results.

Time	Temp. Feed F°	Temp. Delivery F°
3:55	89.0	169.0
3:57.5	89.0	169.0
4:00	89.2	169.0
4:02.5	89.5	168.9
4:05	89.5	169.1
4:07.5	89.7	169.0
4:10	90.0	169.4
4:12.5	90.0	169.8
4:15	90.2	169.8
4:17.5	90.5	170.0
4:20	90.8	169.9
4:22.5	90.6	170.0
4:25	90.6	170.0
4:27.5	91.0	170.2
4:30	91.0	169.8
4:32.5	91.1	169.4
4:35	91.2	170.6
4:37.5	91.5	169.5
4:40	91.5	169.7
Average	90.3	169.9

Reading of Tanks.		
Tank	Inital	Final
Feed	92.6	31.1
Delivery	6.0	72.3

Cu. ft. of water supplied=61.5

Cu. ft. of water delivered=66.3

Steam pressure=100#

Delivery pressure =100#

Calorimeter Readings.				
No.	Steam Pressure	Water Separated #	Steam Run Through #	% Steam
1	110	.07	3.09	97.6
2	110	.07	3.09	97.6
3	115	.07	3.10	97.6
		Average,------		97.6

1. Duration of test=45minutes.

2. Steam pressure (P)=100#

3. Delivery pressure(P')=100#

4. Delivery Head(H)=257 feet.

5. Suction Head =5 feet.

6. Temp. of supply (T)=60°3 F.

7. Temp. of delivery in tank 132.9°F.

8. Lbs. of water supplied per hr. (W)=5006.1

9. Lbs. of water delivered per hr. (W')=5401.2

10. Cu. ft. of water delivered per hr. (C)=88.7

11. Wet steam delivered per hr. (W')=395.1#

12. Dry steam delivered per hr.(W")=385.6#

13. Water delivered per lb. wet steam=13.7#

14. Water delivered per lb. dry steam=14.1#

15. Velocity of discharge in ft. per sec.

$$V=\frac{\text{(cu. ft. delivered) x 144}}{\text{3600(area discharge in")}}=\frac{88.7 \times 144}{3600 \times .040}=73.1$$

16. Energy delivered raising injector water B.T.U. per hr.

$$\frac{W(H \pm H')}{778} \pm W'H'=\frac{5006.1 \times 240 \pm 395.1 \times 257}{778}=1693.2$$

17. Energy delivered heating injector water B. T. U. per hr.

$W(Q-Q')=5006.1\ (138.4 - 58.8) =398485.5$

18. Energy delivered velocity of discharge B.T.U. per hr.

$$\frac{W.V^2}{29 \times 778}=\frac{5401.2 \times (73.1)}{64.4 \times 778}=534.3$$

19. Total energy delivered =

(16) ± (17) ± (18) ± $W'q_t$=

1693.2 ± 398485.5 ± 534.3 ± 395.1 x 138.4 = 458394.3

20. Energy supplied = W'(xr + q)=

595.1(.976 x 876.5 + 308.5)=459896.4

21. Efficiency=$\frac{458394.8}{459896.4}$ = 99.7%

No. of Test.	Log of Results.		Water to Steam %
	Feed Temp. F°	Delivery Temp. F°	
1	52.9	128.9	15.1
2	61.4	137.2	14.5
3	73.9	150.9	14.3
4	80.7	158.2	14.1
5	90.3	169.9	13.7

Conclusion.

The log of results show that an increase of feed temperatures causes a falling off of capacity of injector. This is caused by the reduced vacum within the combining tube.

Tests No. 2, 3 and 4, seem to have about the right variation in capacity, while tests No. 1 and 5 show too great a variation in capacity.

The rather unproportional fall in capacity in tests No. 1 and 5, is due to the fact that the tanks could not be read with enough certainty as the readings were effected no small amount by the temperature.

Our advice in running injector tests is, never use tanks calibrated to read volume but tanks set on scales so that the exact weight of water supplied and delivered can be weighed.