LIFTING INJECTORS

General

1. An injector is a steam jet device by means of which water from the tender of the locomotive can be forced into the boiler against the boiler pressure. Injectors may be of the lifting type or of the non-lifting type, or may operate on a combination of both the lifting and non-lifting designs. All lifting injectors, and some non-lifting injectors, operate with high-pressure steam from the boiler. Other non-lifting injectors are designed to operate with the exhaust steam from the cylinders. Feedwater heating devices are used with some types of injectors.

2. A locomotive always is provided with two independent means of supplying water to the boiler. Each must have sufficient capacity so that in case one fails the other will meet all requirements. The usual practice is to have an injector located on each side of the boiler. The operating handles of the injector on the right side should be within easy reach of the engineer, and the handles of the injector on the left side should be convenient for the fireman to operate. Each injector should be used for a part of the trip. The practice of using one injector exclusively may result in an engine failure because, if this injector fails, the other injector may not be in working condition.

The Principle of the Injector

3. Everyone is familiar with some engineering principles, such as leverage, friction, the effect of heat, etc. The principle which makes possible the working of the injector is not so commonly understood. This principle is called "kinetic" energy. It is defined as the energy which a body has, due to its motion. The faster a body moves, the more momentum or force it will exert if directed against a resistance.

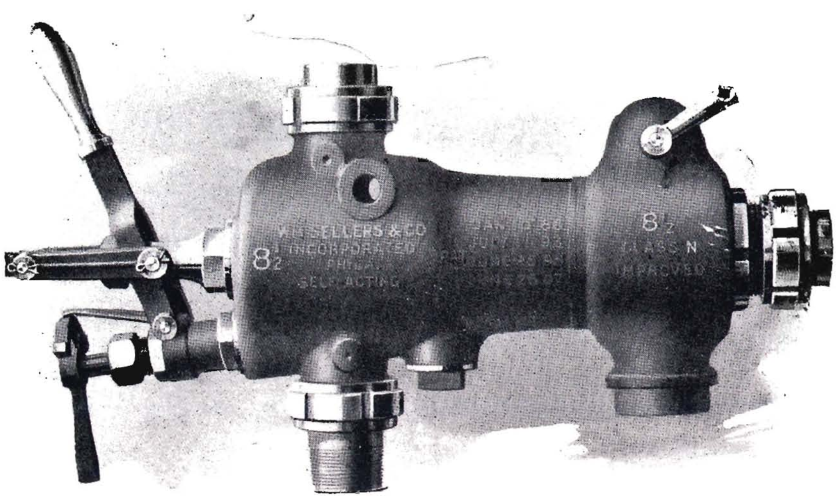

Fig. 1

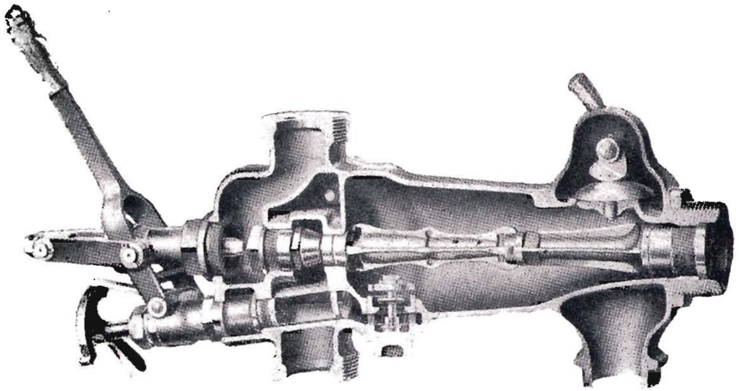

Fig. 2

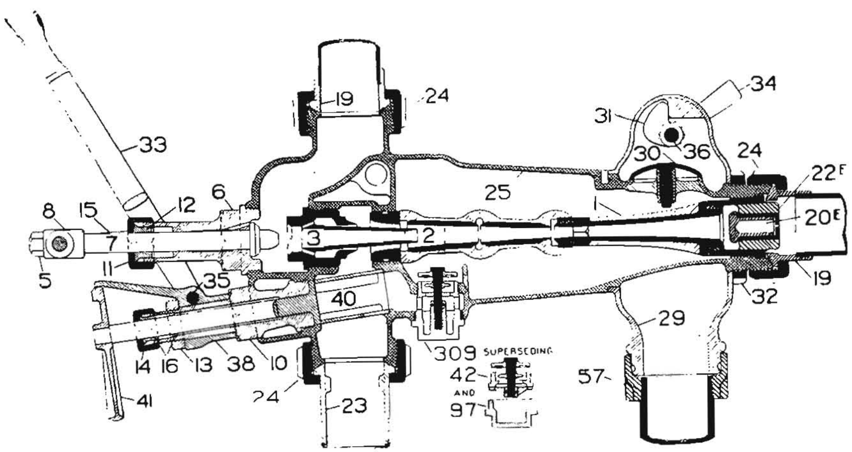

Fig. 3

4. This principle is used in the injector by directing a jet of steam at high velocity into a comparatively slow moving body of water. The water condenses the steam and the energy of the steam is imparted to the moving body of water. The moving body of water is directed through tubes and nozzles, the shape of which further increases the velocity of the stream of water and condensed steam. The design of the injector and its tubes is such that the velocity of the water and condensed steam passing into the delivery pipe has sufficient momentum, or force, to raise the check valve and enter the boiler against the steam pressure.

CAPACITY OF INJECTORS

5. The CAPACITY OF AN INJECTOR is measured in gallons of water per hour that it can deliver to the boiler. The size of an injector for a given locomotive depends upon the steam consumption. It may be determined approximately from the diameter of the cylinders of the locomotive. Tables of sizes and capacities for different cylinder diameters can be obtained from injector manufacturers.

6. The steam supply for the injectors comes from the boiler through the steam turret, or fountain, and is controlled in the injector by a steam valve attached to the operating handle. Exhaust steam injectors use boiler steam for starting, or when the locomotive is standing, but use the exhaust steam from the cylinders at other times.

7. The water supply for the injectors is carried in the tender. It flows past the tank valve to a hose or pipe connection containing a strainer, and then through the water supply pipe to the injector. Atmospheric pressure forces it into the body of the lifting injector when the injector is primed and is operating. It flows by gravity into the body of the non-lifting injector.

8. Lifting injectors usually are located on either side of the boiler and may be a foot or so above the top water line of the tank. Fig. 1 shows one type of lifting injector. The steam pipe is at the top of the body and the water supply pipe at the bottom of the body. The operating handle is at one end of the body and the delivery pipe, which leads to the check valve of the boiler, is at the other end of the body. The second handle below the main operating handle is the water supply regulating valve. The second pipe at the bottom of the body is the overflow pipe.

9. Figure 2 is a cutaway view which shows the valves, tubes, and nozzles of the injector. The main operating parts of a lifting injector consist of a TWO-POSITION STEAM VALVE and a STEAM NOZZLE, a COMBINING and CONDENSING TUBE, and a DELIVERY TUBE. Also, there is a WATER REGULATING VALVE and an OVERFLOW VALVE. Fig. 3 is a sectional view of the injector shown in Fig. 2.

10. Refer to Figs. 1, 2, and 3. The first movement of the operating handle, *33*, opens the steam valve to its priming position. This directs a jet of steam into the combining and condensing tube, *2*. This steam flows out of the openings in this tube and into the body of the injector. The steam raises the overflow valve, *30*, and discharges through the overflow pipe, *57*. This flow of *steam* creates a partial vacuum in the space around the steam nozzle, *3*. The water supply pipe, *23*, is open into this space. As a result, atmospheric pressure forces the water from the tank into the space around the steam valve of the injector, where it mingles with the jet of steam in the combining and condensing tube. The *water* condenses the steam and flows with it through the combining and condensing tube and out of the openings of this tube into the body of the injector and then out through the overflow pipe in a large, slow-moving stream. This action is known as the priming of the injector.

11. As soon as the injector primes, the operating handle is pulled clear out. This completes the opening of the steam valve. As the greatly increased supply of steam is condensed by the water, its added energy is imparted to the water. The greater velocity of the water carries it through the combining and condensing tube and through the delivery tube, *1*, without any overflow or spilling. The delivery tube is shaped as a nozzle. This nozzle imparts additional velocity to the jet of water as it leaves the injector. The stream of water which passes into the delivery pipe has sufficient momentum to force the boiler check valve open and to enter the boiler.

12. An injector is designed with the greatest care. There must be sufficient water supplied to the jet of steam to condense all of the steam. The tubes and nozzles must be shaped and lined up so that the condensed steam and water will form a jet that will pass through the delivery pipe with sufficient momentum to overcome the boiler pressure.

13. The lifting injector will not prime if the water in the supply pipe is too hot. The partial vacuum formed above the water in the supply pipe will allow hot water to vaporize at a temperature much below the ordinary boiling point. Speaking generally, an injector will not prime if the temperature of the supply water is much more than 120 degrees Fahrenheit. Again speaking generally, if the water in the supply pipe enters the injector at a velocity of say 40 feet per second, this velocity will be increased to 180 feet per second or more as it passes through the combining and condensing tube and the delivery tube. At a velocity of 180 feet per second, the stream of water will exert a pressure of 220 pounds per square inch against the boiler check valve.

14. Figures 1, 2, and 3 illustrate a Sellers Self-acting Injector. The principle of operation of this injector has been explained. The lever, *34*, above the overflow pipe provides for the positive closing of the overflow

valve. The part marked *20E* in Fig. 3 is an injector, or line, check valve which operates in case the boiler check valve should stick open. The handle marked *41* is the water regulating valve handle. The movement of this handle increases or cuts down the supply of water to the injector.

15. There is a water inlet valve shown just ahead of the water regulating valve, *40*. When the injector is

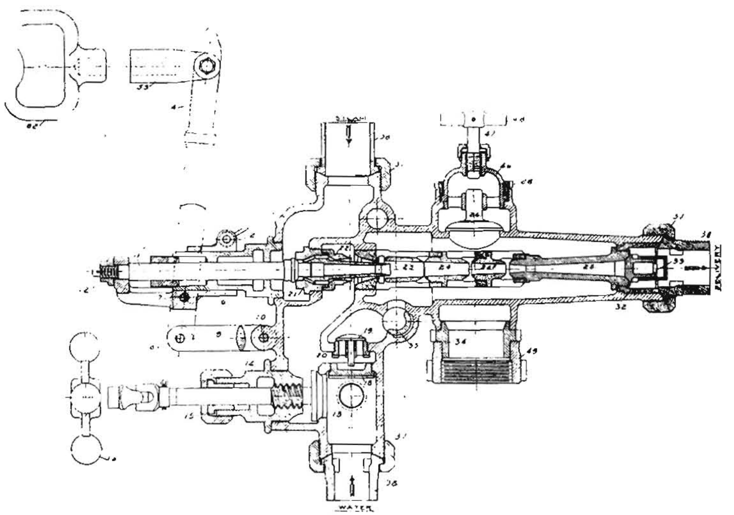

Fig. 4

forcing water into the boiler, the passage of the water through the tubes usually produces a vacuum in the body of the injector. When this is the case, atmospheric pressure on the tank water will force the water inlet valve open, and an additional supply of water will flow directly to the body of the injector. There it will enter through the openings in the combining and condensing tube, and be picked up by the stream of water and condensed steam. This automatically adds to the capacity of the injector. When there is a vacuum in the body of the injector, the overflow valve is held closed by atmospheric pressure.

16. To use the injector to heat the water in the tank in cold weather, the overflow-valve handle, *34,* is

turned so as to hold the overflow valve, *30*, to its seat. The main steam valve leading to the injector is closed off and the operating lever, *33*, is opened wide. Then the required amount of steam is admitted by the partial reopening of

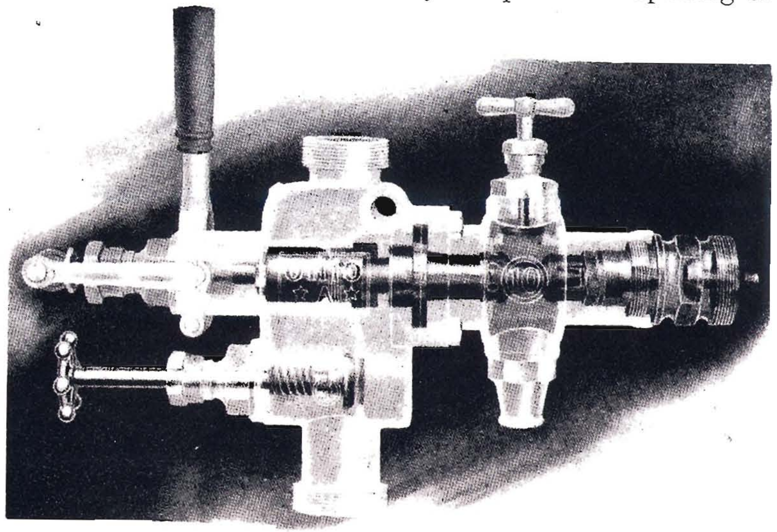

Fig. 5

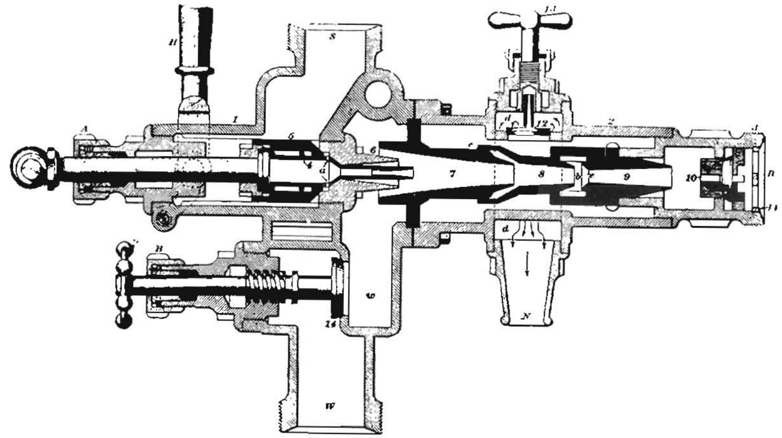

Fig. 6

the main steam valve. To prevent freezing of the overflow pipe, the overflow valve should be adjusted to allow a slight escape of steam past it. The drain in the delivery pipe should be opened also.

17. Figure 4 is a sectional view of the Nathan Manufacturing Company's simplex injector. This type of injector is designed to be self-regulating under variations in steam pressure. Also, it has a restarting feature.

18. Figures 5 and 6 show a phantom view and a sectional view of the Ohio injector. The operation of this type of injector is quite similar to that of the others which have been described. However, the shape and design of the tubes is somewhat different. The Edna Brass Company manufactures a lifting injector quite similar to those already described.

HANCOCK INSPIRATOR

19. Figure 7 is a sectional representation of a form of injector known as a Hancock Inspirator. The significance of the name INSPIRATOR, as distinct from the name INJECTOR applied to other makes of similar apparatus, depends on the double-tube feature of the inspirator.

20. An inspirator of the Hancock type consists of one apparatus for lifting the water and another for forcing; each has its own steam passages, steam nozzle, and combining tube, and each is contained in a chamber separate from the other. There are, therefore, two successive operations in the working of the inspirator: First, the lifting of the water by the lifting half of the apparatus, and second, the forcing of the water into the boiler by the forcing half. This construction gives automatic regulation or governing of the water supply by the lifter tubes. Both steam nozzles receive full pressure when the inspirator is working, so that if the steam pressure in the boiler drops, there will be less steam at a lower temperature passing through the forcing steam nozzle. The forcing part, therefore, will require less water to condense the steam properly. At the same time, however, the lifter tubes lift and deliver less water to the forcer. The Hancock Inspirator also has a positively closed overflow which prevents spilling at the overflow while running.

21. Referring to Fig. 7. The inspirator is started by drawing lever *137* back slightly. This admits steam past the lifter steam valve, *130*, through the forcer steam valve body, *126*, to the steam nozzle, *101*. This steam flowing through the lifter tube, *102*, creates a vacuum above the water in the supply pipe and causes the water to flow

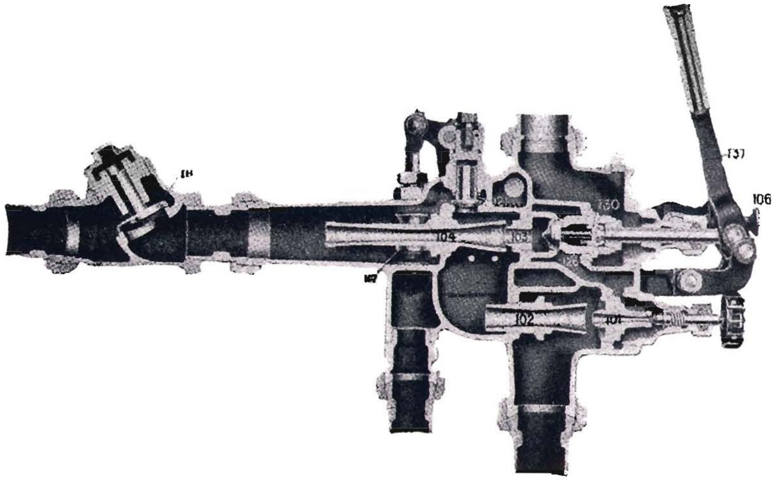

Fig. 7

through the lifter tube, and condense the steam. The stream of condensed steam and water then flows through the intermediate overflow valve, *121*, and out the final overflow valve, *117*. When water shows at the overflow, lever *137* is pulled clear back. This opens the main forcer steam valve, *126*, and admits steam to the forcer steam nozzle, *103*, and to the forcer combining tube, *104*. This creates a pressure in the delivery chamber sufficient to close the intermediate overflow valve, *121*, and open the intermediate, or line, check valve, *111*, as the steam is condensed and the jet formed. When lever *137* is pulled clear back to the stop, overflow valve *117* is closed. When the pin in the wheel of the regulating valve is at the top, the inspirator will deliver its maximum quantity of water. The regulating wheel is turned to the right to reduce the feed.

22. To use the inspirator as a heater, the connecting rod, *106*, is lifted so as to disconnect it from the stud on the lever. The connecting rod then is drawn back, thus closing the overflow valve. Lever *137* now is pulled back to the point used in lifting. This will give all the steam that is required for heating. If the amount going back to the point used in lifting. This will give all the steam regulating wheel to give the amount required. With the lever in the position described, the steam blowing back to the tank passes by the lifter nozzle. Thus, it can be seen that it is unnecessary to handle the main steam valve when using the inspirator as a heater.

LIFTING INJECTOR TROUBLES AND REMEDIES

23. The injector, like any other mechanical device, may get out of order occasionally. The following troubles and remedies are grouped to assist engineers and firemen to locate the cause of trouble quickly, when any occurs, and to remedy such trouble when found. These instructions are general and apply to any type of *lifting* injector.

24. Injector troubles divide into four classes:

First, the injector will not prime.

Second, the injector primes but will not force the water into the boiler.

Third, the injector primes and forces some of the water into the boiler, but spills a part of the water at the overflow.

Fourth, the injector primes and forces, but breaks frequently.

Each of these conditions will be discussed separately. Some of them apply to non-lifting injectors also, as will be explained later.

25. In a great majority of cases, lifting injector trouble is traced to shortage or restriction of the water supply, or to leaks or loose connections in the water supply line to the injector.

INJECTOR WILL NOT PRIME

26. If the injector does not prime, the trouble is due to one of the following causes:

(a) No water in the tank.
(b) Tank valve closed or disconnected shut.
(c) Water supply pipe or strainer clogged.
(d) Injector water valve closed.
(e) Air leaks in the water supply pipe.
(f) Water in the water supply pipe or tank too hot.
(g) Overflow valve closed.
(h) Something wrong with the steam valve, or with the nozzles inside the injector.

27. NO WATER IN TANK. If the injector has been working properly and then fails to prime, the first question should be: Have we run out of water?

28. TANK VALVE CLOSED OR DISCONNECTED SHUT. An inspection will reveal whether or not the tank valve is closed. If it is disconnected, the fact can be told by the "feel" of the valve handle. In case the valve is closed, the remedy, of course, is to open it. If a disk valve is disconnected, usually it can be blown out of place by converting the injector into a heater and using a sufficient head of steam to dislodge the valve. Care should be taken not to burst a hose. Where a siphon pipe is used in place of the old form of tank valve, a pet cock at the top point of the siphon pipe serves the purpose of a tank valve. If the pet cock is opened, the siphon column will be broken. When the pet cock is closed, the vacuum formed in the injector will be sufficient to cause the water to rise to the top of the siphon pipe and re-form the siphon column.

29. WATER SUPPLY PIPE OR STRAINER CLOGGED. If the water supply pipe or the strainer is clogged, the fact can be ascertained by disconnecting the union at the strainer or by taking off the strainer cap. After cleaning the strainer, if it still is thought that the water supply pipe is clogged, the injector may be converted into a heater and the pipe blown out. If blowing the steam back through the pipe seems to clear it but the same trouble immediately reappears when trying to prime the injector again, it may be due to loose lining in the hose which has formed a flap and is obstructing the hose or strainer.

30. The trouble that may arise due to the water supply pipe or strainer being stopped up makes it evident that care must be taken to prevent coal or any foreign substance from getting into the manhole of the tank, either when taking water or at any other time; and that the back of the tank should be kept cleaned off and the manhole cover closed except when taking water.

31. Injector water valve closed. The remedy for a closed water valve is obvious. It should be borne in mind that the position of the handle of an old-style injector may give a misleading indication. If such a case is discovered, the handle should be removed and replaced in proper position.

32. Air leaks in the water supply pipe. Air leaks in the water supply pipe prevent the injector from priming. The leaks prevent the formation of sufficient vacuum to cause the water from the tank to rise up to the injector. Air leaks generally occur around the joints of the pipes and usually are easy to stop. If the leakage is in the hose or at joints that cannot be tightened, an ordinary bandage of canvas, or muddy or oily waste can be bound over the leak. The fact that the leak may be at the pipe connection at the bottom of the injector should not be lost sight of. Leaks in the water supply pipe can be located by converting the injector into a heater, closing the tank valve, and opening the steam valve just enough to cause the leaks to show.

33. Supply water too hot. The water in the water supply pipe or in the tank may get too hot, either by improper use of the heater, or by leaks in the steam valve in the injector or the boiler check valve and line check.

If due to a leak in the injector steam valve or the boiler check valve and the line check, the trouble should be reported so that the proper valve can be ground in.

34. To ascertain whether the leak is at the injector steam valve or at the boiler check valve, the main injector steam valve at the turret should be closed. This will stop a leak in the steam valve. If the leak is at the boiler check, closing this main steam valve will have no effect. A leaky boiler check and line check also may be indicated by a drip of water and steam at the overflow pipe. If the trouble is due simply to the water in the water supply pipe being too hot, the injector may be used as a heater to blow this hot water back into the tank. The cool water from the tank coming back into the water supply pipe will allow the injector to prime properly.

35. If the trouble is due to the water in the tank being too hot, the proposition is more serious and the only chance to get the injector to work is to reduce the steam pressure by means of the steam valve at the fountain. The injector may prime when the pressure is reduced. The heater must be watched so that the water in the tank will not get too hot. After one half or two thirds of the tank of water has been used, the remainder heats up very quickly.

36. To understand why hot water in the tank or water supply pipe will prevent an injector from priming, it must be remembered that water will boil at a temperature depending on its pressure. Water in a teakettle will boil at 212 degrees Fahrenheit, but water in a boiler carrying 200 pounds of steam will not boil until the temperature is about 387 degrees. On the other hand, water in the injector water supply pipe will boil at a temperature considerably less than 212 degrees when the priming vacuum is formed. Consequently, steam will form in the pipe and supply the vacuum that otherwise would cause the water to lift.

37. OVERFLOW VALVE FASTENED SHUT. The overflow valve has to be open during the priming operation.

38. OTHER CAUSES. If none of the foregoing causes proves to be at the bottom of the trouble, then it is probable that something is wrong inside the injector. The trip can be finished with the other injector, and the trouble reported so that it can be remedied.

THE INJECTOR PRIMES BUT WILL NOT FORCE THE WATER INTO THE BOILER

39. If the injector primes but will not force the water into the boiler, the trouble is due to one of the following causes:

(a) Obstruction at the boiler check valve.

(b) Obstruction at the line check.

(c) Obstruction in the delivery pipe.

(d) Dirt or some obstruction in the delivery, or the combining and condensing tubes.

(e) Steam valve to injector not fully open.

(f) Not sufficient water to condense the steam, due to the water valve or the tank valve not being wide open, or to air leaks in the suction pipe, or as a result of the strainer or suction pipe being partially stopped up.

40. BOILER CHECK VALVE STUCK SHUT OR WILL NOT OPEN WIDE. In this case the injector will prime but will not force the water into the boiler because the volume of water carried to the check valve cannot pass it, owing to the obstruction.* As a result, the stream or jet backs up and breaks. If the amount of steam and water entering the injector is cut down, it may be possible to work the injector at reduced capacity, provided the check valve is not stuck entirely shut. It is possible in some cases to loosen the check valve so it will reseat by dousing it with a pail of cold water or by tapping the check-valve casing.

*Closing the boiler stop valve at this check valve does not *remedy* the trouble, it simply prevents blowback of water and steam.

Many engine failures are caused by hammering the check valve with a hard metal hammer or coal pick. This not only spoils the check, but may weaken it so that it lets go. The check-valve casing never should be hit except by a wooden mallet or block, or by a soft hammer, and then it should be tapped very lightly.

41. OBSTRUCTION AT THE LINE CHECK. The same trouble as stated occurs and the same means for trying to remedy the trouble apply when the line check is stuck shut, or is stuck so that it opens only partially.

42. OBSTRUCTION IN THE DELIVERY PIPE. The effect of an obstruction in the delivery pipe is the same as that of an obstruction at the boiler check valve or at the line check.

43. DIRT OR SOME OBSTRUCTION IN THE DELIVERY, OR THE COMBINING AND CONDENSING TUBES. In this case, the dirt or obstruction either breaks up the jet of water, or destroys its true form so that the water does not all pass by the spill openings of the tubes. The velocity of the water through the delivery nozzle is thereby decreased. Lack of velocity means lack of sufficient pressure in the delivery pipe to lift the boiler check. The injector therefore stalls and breaks. The trouble should be reported at the end of the trip, so that it may be repaired at the shop or roundhouse.

44. STEAM VALVE NOT FULLY OPEN. This may cut down the velocity of the jet enough so that the water will not force the boiler check open.

45. NOT SUFFICIENT WATER TO CONDENSE THE STEAM. This may be due to air leaks in the water supply pipe; to the strainer or water supply pipe being partially stopped up; or to the tank valve or water valve on the injector not being wide open. The reason for the failure under such conditions is that all of the steam passing by the steam nozzle must be condensed by the water, in order to have the stream or jet form properly. If all of the

steam is not condensed, the uncondensed steam will cause the injector to "break." The proper remedy for this trouble is to stop the leaks, clean out the strainer or water supply pipe, or open up the tank valve or water valve. The injector perhaps can be made to work, even under these improper conditions, if the steam pressure is reduced by a partial closing of the injector steam valve. This may allow the restricted water supply to condense the reduced amount of steam.

THE INJECTOR PRIMES AND FORCES BUT SPILLS SOME OF THE WATER

46. If the injector primes and forces, but spills some of the water at the overflow, the trouble may be due to one of the following causes:

(a) Slight obstruction at the boiler check or line check, or a partial obstruction of the delivery pipe, preventing the passage of the full capacity of the injector.

(b) Slight obstruction in the injector tubes, which diverts some of the water to the overflow instead of letting it pass as a solid stream to the boiler.

(c) Improper regulation of the steam and water supply.

47. A SLIGHT OBSTRUCTION AT THE BOILER CHECK OR LINE CHECK, OR A PARTIAL OBSTRUCTION OF THE DELIVERY PIPE. This may allow the injector to force the greater portion of the water into the boiler, but the remainder will spill at the overflow. This will not happen unless the amount of water passing into the boiler is sufficient to hold the stream rather solid so that only a small amount of the water spills.

48. SLIGHT OBSTRUCTION IN THE INJECTOR TUBES WHICH DIVERTS SOME OF THE WATER TO THE OVERFLOW INSTEAD OF LETTING IT PASS AS A SOLID STREAM TO THE BOILER. In the case of a slight obstruction in the tubes of the injector—not sufficient to break up the jet or stream of water—the injector will force the greater portion of the water into the boiler. That part of the stream which is deflected by the obstruction will spill at the overflow. If the injector tubes have become pitted due to bad water, the effect may be about the same as that due to a slight obstruction.

49. IMPROPER REGULATION OF THE STEAM AND WATER SUPPLY. Injectors are designed to work properly under certain conditions of steam and water supply. If too great a supply of either steam or water is furnished to the injector, it will not work properly. If the supply of steam is much greater than the supply of water, but there is sufficient water to condense practically all of the steam, the injector will force most of the water into the boiler but the stream will not form properly in the tubes and some of the water will spill. The water that spills will be hot and will show steam. This is an indication that there is too much steam or too little water. The opposite condition (where there is too much water and too little steam) produces the same result, except that the water spilling at the overflow is cold and no steam shows.

50. The inside of the injector tubes may become covered with a deposit of lime or other substances, especially in bad-water districts. This deposit reduces the size of the tubes, and may be a source of trouble that will have the same effect as too much steam for the supply of water that can enter the tubes.

INJECTOR PRIMES AND FORCES BUT BREAKS AGAIN

51. If the injector primes and forces, but after forcing for a short or a long time suddenly breaks, and this action is repeated frequently, the trouble may be due to one of the following causes:

(a) Leaks in the water supply pipe that are caused by the jarring of the engine; loose connections at the hose or feed-pipe couplings that open on curves or rough track; or kinks in the hose.

(b) Water low in the tank so that the motion of the water leaves the tank valve dry at times.

(c) Tank cover airtight.

52. Leaks in the water supply pipe that are caused by sudden jarring of the engine; loose connections at the hose or feed-pipe couplings; or kinks in the hose. These leaks may not affect the working of the injector when the engine is standing, nor when it is running along without much vibration or jarring, but on curves or rough track, or when any unusual jar or spring of the engine occurs, the working of the loose pipe or joint, or the stretching or kinking of the hose may cause the injector to break. An indication of such trouble is given by a rumbling noise from the injector while it is working. This noise is caused by air passing through the injector with the water. A close inspection of the pipes, hose, and couplings should result in locating this trouble. It must be borne in mind that while everything *apparently* may be all right when the engine is standing still, nevertheless something *is* wrong.

53. Low water in the tank. When the water in the tank gets quite low, the swaying of the tank, or the running in or out of the slack of the train, may cause the water to uncover the tank valve. This will cause the injector to "break." The remedy for this is to fill the tank as soon as possible. It may be necessary to "run for water." If the water in the *boiler* gets low also, a light application of the brakes while the train is running at a fair speed will cause the water to bank up against the front of the tank so that both injectors can be started. In this way, some slight gain can be made in the water level in the boiler that perhaps may save having to kill the fire for safety.

54. Tank cover airtight. The tank cover may become airtight in winter on account of the formation of ice around the manhole. Then, as water is withdrawn from the tank, the pressure of the air in the tank will

reduce also, until it will no longer continue to force the tank water to the injector. When this occurs, the injector will "break." The remedy for this is obvious.

1/19/15

Steam Injector Calculation
Determine nozzle velocity
needed to develop 200 psi of pressure!

Kinetic Energy$_1$ ≈ Flow Energy$_2$

$$\frac{1}{2} m \bar{V}_1^2 = P_2 V_2$$

$$\bar{V}_1 = \sqrt{\frac{2 P_2 V_2}{m}} = \sqrt{\frac{2 P_2}{\rho_2}}$$

$\bar{V}_1$ = velocity
P_2 = final pressure
V_2 = Volume
m = mass
ρ_2 = density

$$\bar{V}_1 = \sqrt{\frac{2}{} \left| \frac{200\ \cancel{lb_f}}{\cancel{in^2}} \right| \frac{ft^3}{62.4\ \cancel{lb_m}} \left| \frac{32.2\ \cancel{lb_m}\ ft}{\cancel{lb_f}\ s^2} \right| \frac{\cancel{144}\ \cancel{in^2}}{ft^2}}$$

$$\bar{V}_1 = \underline{172} \frac{ft}{sec}$$

or $\underline{118}$ mph