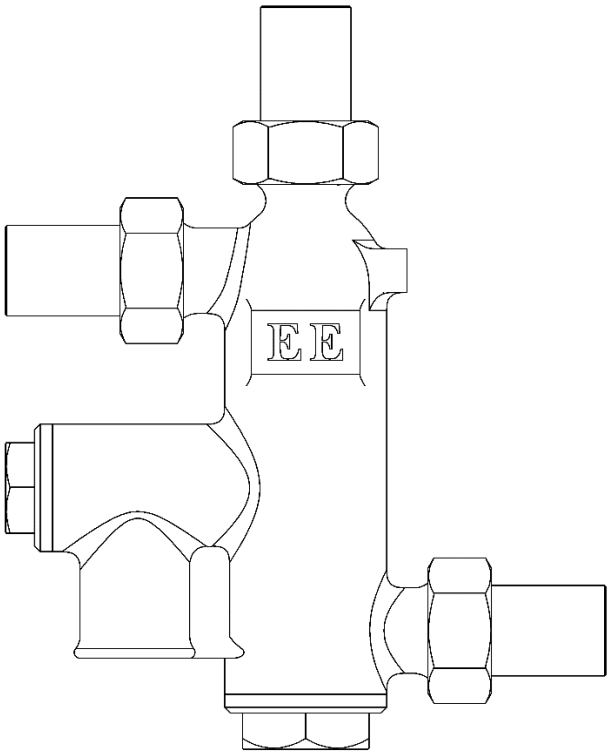
# Injectors

## A General Guide

to the Model Automatic Injector

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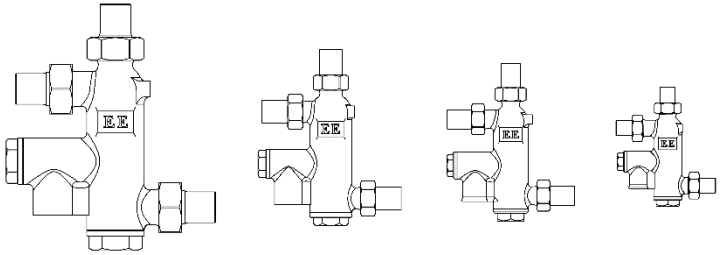


## Preface

The purpose of this booklet is to review the function, operation, maintenance, and installation of injectors. Many of the principles will apply to any injector, however the focus is first and foremost on the injectors offered by Eccentric Engineer. The information will also be applicable to SuperScale and Ohlenkamp (E.M.) injectors, but their capacities, operating range, and connection sizes differ from the Eccentric Engineer line of injectors. The information in this booklet is not universally applicable to the British style model injectors.



## How They Work

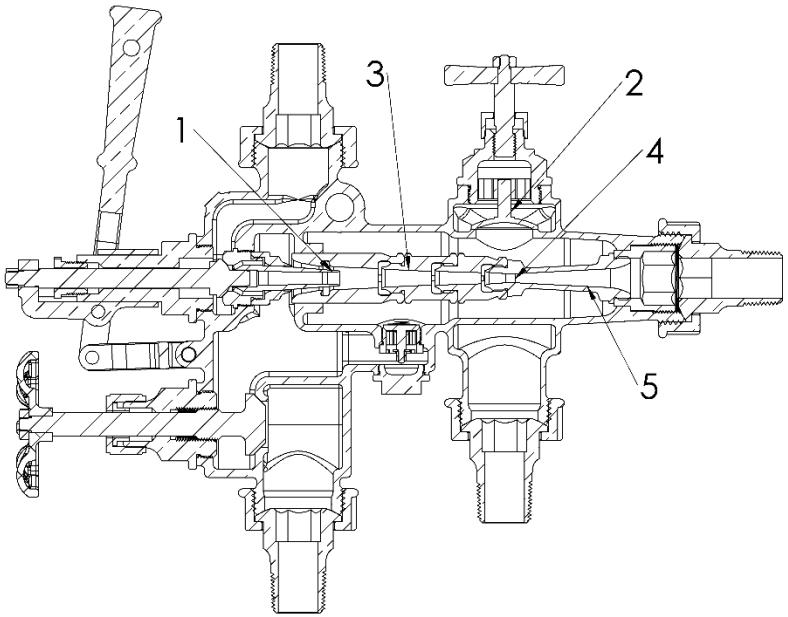
Most explanations include words like “Venturi,” the “Bernoulli Principle,” or “thermal expansion.” All these things are undoubtedly happening inside an injector, but they have little to do with why they work. These principles don’t alone explain why the output pressure is higher than the boiler pressure.

There’s one term that almost never comes up, but it’s the primary principle that’s at work: **conservation of momentum**.

Imagine a game of billiards, but instead of trying to land a ball in a pocket, the objective is to force a ball through a trap door (i.e. check valve). The door is spring loaded, and the ball can only be shot toward the door with a momentum that is equal to the force holding the door shut. It can never go through on its own unless it is struck again with a second ball while the first ball is already in motion toward the door.

Imagine the same scenario but scaled down to a molecular level. That first ball that can’t overcome the door’s force is a single molecule of steam that’s been shot out of the steam nozzle, and the second ball that gives it the extra push is water. But it’s not just one water molecule, it’s approximately 4,400 water molecules for every 1 steam molecule. That’s a significant push! Conservation of momentum dictates that the steam’s momentum is not lost when the water enters the jet, but rather the water’s momentum is added to the steam’s momentum, giving it that extra push needed to open that check valve. That extra push translates to a pressure differential, where the output pressure is higher than the initial boiler pressure.

The Venturi helps draw in the water, the Bernoulli Principle allows the steam and water to travel through the condensing nozzle without blowing back to the water source, and the heat transfer preheats the water as a massively efficient bonus!




**1** – When steam is turned on, steam pressure is converted into a high velocity jet of steam through the steam nozzle. A strong vacuum (venturi) forms at the tip of this nozzle, drawing water into the body, which enters the gap between the steam nozzle and combining nozzle.

**2** – The overflow allows the initial blast of steam to escape freely while water is being entrained into the injector. Without this, steam blows back into the water line rather than forming a constant vacuum.

**3** – Once water enters the jet of steam, the steam rapidly condenses back into water. As it's forced through the condensing nozzle, it continues to gain velocity and the pressure drops (Bernoulli Principle).

**4** – The smallest point of the delivery cone sees the greatest velocity, and its diameter is the primary factor in an injector's delivery capacity.

**5** – The diverging delivery cone slows down the mass of water, effectively converting it back into pressure. Due to the added momentum from the water, the resulting pressure is higher than the original boiler pressure.



## INSTALLATION

The following diagrams are intended to highlight the most important elements of proper injector installation and are by no means a strict guide to how it must be done. There is great flexibility, as long as certain principles are kept in mind.

First, some frequently asked questions:

**Do I need a quick opening steam valve?**

NO, you absolutely do not. Quick opening valves will work fine, but a globe valve or ball valve will also work just fine. There are truthfully more advantages to using a globe valve over a quick starting valve, but that will be discussed more in chapter 5.

**Do I need a water adjustment valve?**

YES, and not just any valve will do. Injectors draw in significantly more water than they can deliver, so it is important to be able to choke back the water to the injector for it to operate correctly. A globe valve is strongly recommended. The fine adjustment is extremely useful, especially at lower pressures. A ball valve will work too and will operate adequately if its size is not disproportionately larger than the injector's tubing diameter.

**Can I have sharp bends in my lines?**

YES, but sparingly. It's best to have simple lines with gentle bends, but two or three 90° elbows will not have a negative impact your injectors performance. The most important thing is to not use any fittings with too small of an inner diameter.

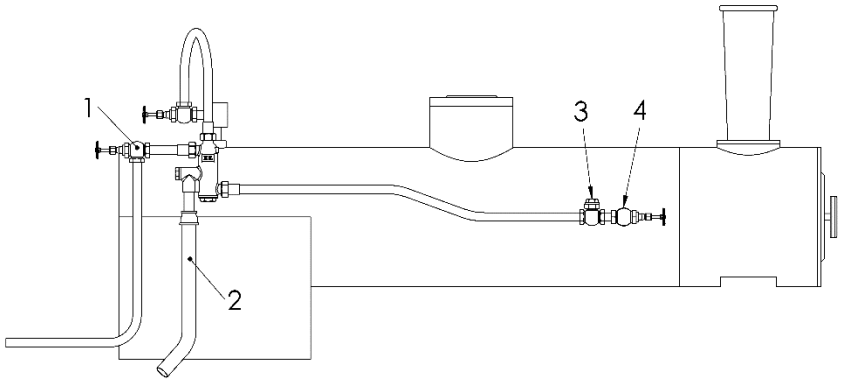
**Do I need a water filter?**

YES, yes, and YES. Installing a suitable filter on your water line is the #1 best preventative maintenance you can do for your injector. Particles lodged into the small cones are the primary cause for injector problems.

50 micron Inline fuel filters from Dorman work great, come in multiple sizes, and can be disassembled to replace the filter.

## Lifting Installation

EE's injectors are designed to lift greater distances than would ever really be necessary on a model boiler, but there are a few things you must be mindful of for the injector to lift quickly and reliably every time.




**1 –** The placement of the water valve is not critical, as long as it is somewhere where it can be easily reached. The strongest vacuum in the water line forms between the adjustment valve and the injector, so it's imperative to use as few fittings as possible between these two points. This reduces the likelihood of an air leak, and even the slightest air leak in any fitting will cause the injector to fail.

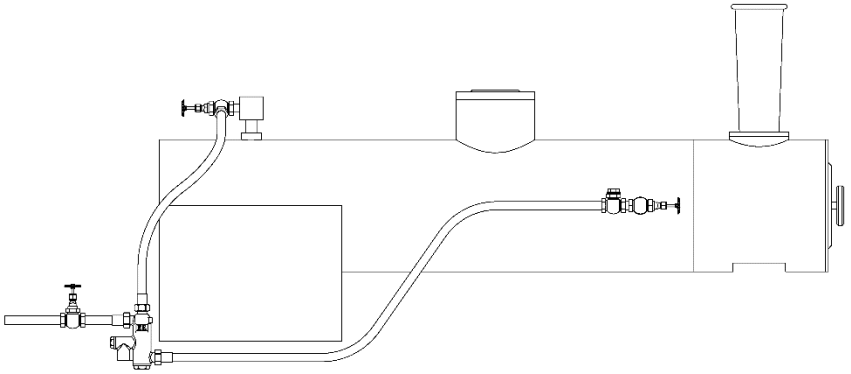
**2** – If the overflow tube is exceptionally long, it's recommended to step up the tubing size, but it is not required. Drilling a small hold in the overflow close to the injector will help to prevent water from siphoning out of the tender.

**3** – A poppet or flapper style check valve is strongly recommended. Be sure to use a valve that has the same diameter as your tubing, i.e., if the injector is designed for 1/4" tubing, use a 1/4"-MTP check and valve. Ball check valves are more likely to have issues with flow restriction.

**4** – A shutoff valve between your check and your boiler is strongly recommended. If the check leaks or fails, you can shut off the line to service the check valve while the boiler is under steam. The injector will not operate against a leaky check valve.

## Non-lifting Installation

Perhaps the most common installation method is to place the injector below the tender level. The same precautions must be taken as illustrated in the lifting diagram, except there is no need to extend the overflow tube.



## General Precautions / Recommendations

The water adjustment valve will be more responsive the closer it is to the injector, however it does not have to be as close as shown. Many use ball valves under the tender, which works great but does allow more potential for air leaks. Again, use as few fittings as possible between these two points. Compression fittings are not recommended for use on the water line, and it is strongly recommended to have an independent, isolated water line for the injector.

Whether lifting or non-lifting, be mindful of the water line's proximity to the firebox. If there is enough heat radiating to pre-heat the water inside the line, the injector will blow misty steam for a lengthy amount of time (30-60 seconds) before cycling through the heated water. Also be sure not to mount a bracket off a hot surface. The heat will transfer into the bracket and subsequently to your water line, preheating the water. Injectors work best with 60°-70° feedwater.

Install plenty of unions where sensible. Disassembly for future maintenance is significantly easier if your piping can be taken apart in more manageable pieces.

# Operation

## How to start the injector

Eccentric Engineer injectors are ‘automatic,’ meaning they will pull in water and self-prime without gravity feed. This also means if the flow of water is interrupted for any reason, the injector will automatically restart after the interruption. What this means in operation is it doesn’t matter whether you open the water or steam valve first.

That said, it’s common practice to first open the water valve fully then the steam valve. With the water and steam valve fully open, water should gush out of the overflow. Gradually close the water valve until nothing is coming out of the overflow. If it’s running ‘dry,’ and the steam and water valve are open, then the injector is working. Due to the automatic action of these injectors, you can also turn on the steam first, then gradually open the water valve until the injector picks up and the overflow runs dry.

## Advantages of lifting

When the injector is installed above the height of the tender, water will not pour out of the injector with the water valve open. This means the valve can be set to an ideal position for your operating pressure and left open. Then, when its time to put water in the boiler, all that must be done is open the steam valve. This also makes it impossible to drain the tender by accidentally leaving the water valve open.

## Throttling

Although injectors have an advertised delivery rate, their capacity is variable by adjusting the water valve while the injector is operating. Maximum delivery occurs with the steam valve fully open, and the water valve open to the point where the overflow just starts to drip. Minimum delivery rate can be achieved by closing the water valve until the injector just starts to drip. The capacity can be reduced to approximately 60% of the injectors max delivery rate at the current boiler pressure. Ability to throttle is reduced at the lowest extreme of the injector’s pressure operating range.



# Dispelling Myths

1) **Injectors won’t work with sharp bends on the delivery line**
   This is simply not true. This stems from the misunderstanding that the velocity inside the delivery line is what overcomes the boiler check, but the velocity in the nozzles has already been converted back into pressure due to the delivery cone. If the I.D. of the tubing and fittings is appropriately sized, the injector will work fine with sharp bends.

2) **Injectors should be installed down low for reliability**
   This is generally true for the British style model injectors, but it is not even remotely true for Eccentric Engineer, SuperScale, or Ohlenkamp injectors. The problems that tend to arise with these injectors cannot be resolved by installing the injector below the tender.

3) **Injectors work better with a quick start valve**
   It is a miracle that these little injectors work at all with quick start valves. No full-sized injector will operate without first being gently primed. Even lifting injectors had a separate priming nozzle. Globe valves and ball valves both work great for starting an injector and can be easily cut back to properly throttle down the capacity. This adds some versatility to the way an engine can be fired, whereas a quick start valve does not.

4) **Injectors can’t lift if the feedwater is warm**
   This is perhaps more an issue of semantics. It is true that injectors don’t work once the feedwater gets too warm, but that doesn’t mean they don’t lift. They will still lift warm water up into the body, but if the water is too warm, the steam won’t be able to condense fast enough to combine with the water. The overflow will sputter steam and mist until it eventually . If it’s a particularly hot day, throw some ice in the tender!

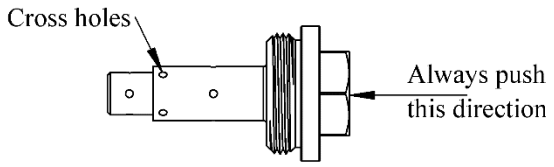
**5) Soak in vinegar to clean the cones**

EE's nozzles are now made from 316 stainless steel, so use a feel free to use a solvent of your choice. HOWEVER, soaking brass injector cones in vinegar can etch the internal surfaces rapidly accelerating wear and erosion. Please, just don't do it! The safest way, which is vastly more effective than vinegar, is to clean the cones in an ultrasonic cleaner for 2-3 minutes with 50/50 CLR and water. Cheap ultrasonic cleaners are available at Harbor Freight.

**6) Never use metal to remove a blockage**

It goes without saying that one shouldn't blindly gouge the internal tapers with metal, but properly sized wire or a gauge pin works miracles for removing tightly lodged particles. The trick is to always push out the obstruction from the bottom of the delivery cone backwards toward the end with the cross-drilled holes. Push it through once, then blow out with air. Once the delivery tube is clear, the cross holes can be checked and cleaned.

Below is a chart for wire gauges and pin gauge sizes that are suitable for removing obstructions from the delivery cone:




| | Wire Ga. Delivery | Gauge Pin Delivery | Wire Ga. Cross Holes | Gauge Pin Cross Holes |
|---|---|---|---|---|
| **Small** | 21 | .030 | 25 | .019 |
| **Intermediate** | 18 | .041 | 23 | .025 |
| **Standard** | 17 | .048 | 21 | .03 |
| **Large (6.5 pint)** | 16 | .053 | 20 | .034 |
| **Large (8 pint)** | 15 | .061 | 18 | .042 |

THIS CHART APPLIES *ONLY* TO EE INJECTORS



## TROUBLESHOOTING

The following is a list of typical problems, the symptoms they exhibit, and how to find and fix the problem.

### Air Leaks

Symptoms: Constantly sputtering overflow, injector is more sensitive at lower pressures

Solution: To determine which fitting is drawing in air, turn on the injector and choke back the water until the injector sounds like it's trying to deliver. While it's sputtering, pour water from a hose over every joint on the water line one by one. If a fitting is drawing in air, the water will temporarily seal the compromised joint and the injector will pick up while the hose is over the leaky fitting. Once the leak is identified, seal the joint accordingly.

### Clogged Steam Cone

Symptoms: Steam does not come out of the overflow, or steam blast is relatively weak.

Solution: Remove steam cone from the top of the injector and blow out debris.

### Clogged Delivery Cone

Symptoms: Unable to draw in water, steam blowing back into tender, injector primes but does not inject.

Solution: Remove delivery cone and inspect for any obstructions. If blowing out with compressed air does not clear the debris., refer to the chart in Chapter 4 for appropriately sized wire or gauge pins to push out the obstructions. If problem persists, add a filter to the water line.

### Seized Washer

Symptoms: Draws in water normally but will not deliver when choking down the water valve. Symptoms comparable to an air leak.

Solution: Remove delivery cone with seized washer and soak in WD-40 or Kroil. Remove washer and clean surfaces until the washer moves freely. Tapered side of washer faces down!

### Overheated Injector / Water Line

Symptoms: Blows steam for a long time before drawing in water, will only pick up by pouring water over body.

Solution: EE Injectors can still promptly draw in water even if the body is at boiler temperature, but there may be a slight delay as the water flashes into steam. Some things can exacerbate this delay: warm feedwater, or a long overflow pipe if it is not enlarged. Make sure the overflow can breathe freely, and that there is no way the feedwater line is getting warm.

### Priming / Foaming

Symptoms: Injector starts momentarily and promptly breaks

Solution: If the boiler is overfilled, or foaming due to contamination in the boiler, water or foam can easily make its way into the injector. Injectors will not work with anything but dry steam.

### Injector Installed Backwards

Symptoms: Unimpressive gravity flow if non-lifting, steam blows back into tender, injector will not work.

Solution: Double check diagrams to ensure injector is oriented correctly. If not, reinstall in the proper orientation.

### Injector Fighting a Pump

Symptoms: Injector works fine when stationary, but not while moving

Solution: If the injector is sharing a suction line with an axle pump or steam pump, isolate the injector line if possible, or make sure your water adjustment valve is placed after the tee where the line separates to the two devices.

### Missing steam cone

Injector only blasts steam and does not pick up water. Make sure the steam cone did not fall out!



## Sizing An Injector

To calculate the required injector capacity for a steam engine, the maximum water consumption must be calculated. The following variables need to be determined:

- Operating PSI (pounds per square inch)
- Cylinder Bore Diameter (B, in inches)
- Cylinder Stroke ($S_1$, in inches)
- SPR ($S_2$, powered strokes per revolution)
- Max cutoff percentage in full gear (C, percentage as a decimal)
- Driver diameter (D, in inches)
- Max operating speed (in MPH)

First, to calculate the max volume of the cylinders we must multiply the area of the bore and multiply it by the stroke, then multiply it by the cutoff percentage and number of strokes.

$$\pi\left(\frac{B}{2}\right)^2 \times S_1 S_2 C$$

Example of a 3” x 4” 2-cylinder engine with 75% max cutoff:

$$\pi\left(\frac{3in}{2}\right)^2 \times 4spr \times 4in \times .75 = 84.823\ in^3$$

Now the max operating RPM must be calculated.

$$\frac{MPH \times \frac{63360in}{60min}}{2\pi\left(\frac{Din}{2}\right)} = rpm$$

Let’s assume a driver diameter of 7 inches and a max operating speed of 7 mph.

$$\frac{7mph \times 1056ipm}{2\pi 3.5in} = \frac{7392ipm}{21.99in} = 336.13rpm$$

Now the RPM and max volume per revolution must be multiplied to determine how much volume steam occupies in 1 minute at max speed.

$$84.823in^3 \times 336.13rpm = 28{,}511.55in^3\ per\ minute$$

There are $28.875in^3$ to a pint. Why pints? Well for some reason they have become a standard unit of measurement for the delivery rate of model injectors. So,

$$\frac{28{,}511.55in^3\ per\ minute}{28.875in^3} = 987.41\ pints\ per\ minute$$

So just how much room temperature water fits inside of 987.41 pints of steam at your operating pressure? First we need to know the density of steam based on your boilers max PSI. Here's a brief table for some typical operating pressures:

| PSI | Steam Density lb/in$^3$ |
|---|---|
| 100 | ≈.0001324 |
| 125 | ≈.0001593 |
| 150 | ≈.0001860 |

Assuming the boiler is operating at 125psi, we need to know how much room temperature water is used out of 987.41 pints of steam. The density of room temperature water is .036 *lb/in*$^3$

$$987.41\ pints/min \times \frac{.0001593lb/in^3}{0.036lb/in^3} \approx 4.37\ pints/minute$$

4.37 pints per minute is the theorical maximum this engine would consume working its hardest at maximum pressure. However, steam is being consumed in other ways. Steam pumps, blower, various steam leaks, perhaps a working dynamo. Eccentric Engineer recommends a safety factor of at least 1.5x to ensure you can still fill your boiler while working hard. This translates to a recommended capacity of 6.55 pints per minute, or the 6.5 pint per minute variant of the EE Large Injector.

## Operating Peratmor Data

| Injector | Capacity | Tubing | Operating PSI |
|---|---|---|---|
| Small | 2 ppm (32oz) | 3/16" or 1/4" | 35-150psi |
| Intermediate | 3.75 ppm (60oz) | 1/4" | 35-150psi |
| Standard | 5ppm (80oz/min) | 5/16" | 35-150psi |
| Large | 6.5ppm (104oz) | 3/8" Tubing or | 50-200psi |
| Large | 8ppm (128oz) | ¼" NPT | 50-200psi |

**Approximate Recommended Sizing at 125psi operating pressure**

| Cylinders | Max Consumption | Injector |
|---|---|---|
| **1.25" x 2.25"** | 1.75 ppm | Small |
| **1.50" x 3.00"** | 2 ppm | Small |
| **1.75" x 3.25"** | 2.7 ppm | Intermediate |
| **2.00" x 3.25"** | 2.8 ppm | Intermediate |
| **2.50" x 3.50"** | 4.45 ppm | Standard |
| **2.75" x 3.50"** | 5.29 ppm | Standard |
| **3" x 4"** | 6.5 ppm | Large (6.5ppm) |
| **4" x 5"** | 9 ppm | Large (8ppm) |

If you are not sure what size you need feel free to reach out to Eccentric Engineer for a recommendation!

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