Eductor pumps: the calculations

The eductor pump, or 'ejector', is as old as the Greeks, but it is not as well utilised as the centrifugal pump with which it shares some performance features. The principal reason is the poor overall power efficiency, but lack of use creates lack of familiarity. In fact, if treated just as a water-operated suction pump the eductor is embarrassingly simple and becomes another tool in the skilled pump man's range. Trevor Benjamin describes the principles of how it works, provides guidance on how it can be applied and gives a procedure selecting the right dimensions.

A centrifugal pump will deliver two or three times as much water as an eductor pump for the same power, it is smaller and familiar. The eductor pump however survives in corners of the fluid handling field where power is not the first consideration and other problems come higher on the list. They can be totally unsuitable for ninety nine applications-but fit one like a glove.

The eductor pump: how does it work?

If a fire jet is pointed at the surface of a lake the water moves away in eddies from the point of impact. The energy in the fire jet has been transferred to the water in the lake and that water has now been moved on.

The same` effect takes place when the white snooker ball is sent down the table at high speed. The reds scatter , mainly in a direction away from the cue ball. The cue ball slows up having parted with its energy in hitting the reds.

An eductor pump comprises a jet of fluid and a collecting pipe. The only moving parts are the fluids. The energy in the power fluid is imparted to the entrained fluid in the collecting pipe and both are moved on.

Terminology

At this point it is worth defining our terms. As most pumps handle water or air, the terms water and air will be used in the rest of this article as a general description . Fluids of all sorts can be handled, including slurries and fluid borne trash and particulates.

- Air/air
- Air/liquid
- Liquid/air
- Liquid/liquid
- Combinations.

The range is wide. Eductors are being used, powered by gaseous ammonia to transfer lubricating oil in refrigeration plants. They are used to create exceptionally high vacuums with liquid ring pumps. They shift muds and slurries and they extract drinking water from deep wells. Steam as the gas power is particularly effective in power stations.

Even sand can be pumped using the eductor pump as a mixer and the water as a conveyor.

Air/air

Air eductors are vacuum pumps and have application where great reliability is required, possibly under dirty or corrosive conditions. They also permit very high vacuums to be achieved as second stages to mechanical vacuum pumps.

Air/liquid

The scent spray uses compressed air from the rubber bulb to force a jet of air across the top of a dip pipe in the scent bowl. This lifts the scent and directs it at right angles , pumping it where needed. Using compressed air to move a liquid has the drawback that the discharge is expansive and the liquid is spread into the open world in drops that are difficult to re-coalesce. The scent spray, the paint gun and the carburettor however exploit this 'drawback' fully. The eductor is more common than we realise.

Liquid/air

Many laboratory sinks have small water operated vacuum eductors fitted to their taps so that at a turn of the water tap a suction may be applied to a filter funnel, for instance. The filtrate can be washed away down the sink with the power water.

Liquid/liquid

This article will concentrate on the more conventional pumping of liquids. The diluting effect of the drive water has great benefit in keeping slurries moving in the discharge pipe and the deep suction

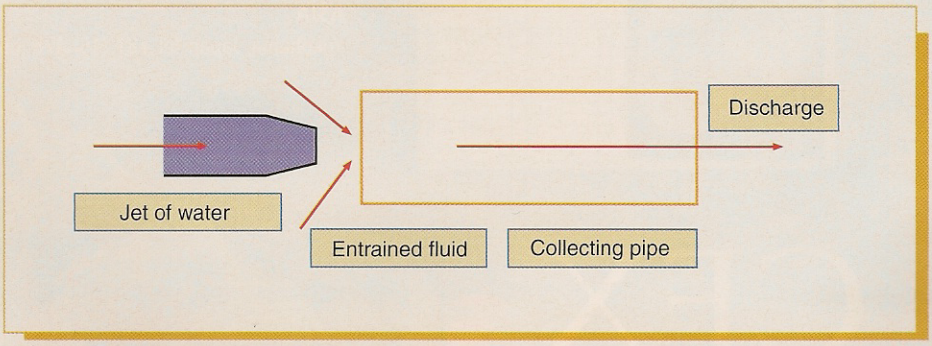

Figure 1. Basic principles of the eductor.

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capability can be exploited in pumping difficult liquids from inaccessible places.

The calculations differ for compressible fluids and this article will concentrate on the fluids you will most likey to need to consider and the Liquid/Liquid pump.

Shape and size

A tubular tee shape with a side inlet is the most common for large versions. Deep well pumps have a 'U' shape with a bottom inlet. This allows them to fit snugly down a well. Slim versions are available in which the pressure pipe and the discharge pipe are concentric and give the appearance of a single hose. They are very manageable and if the pipe is flexible hose they have the operating feel of using a vacuum cleaner .

Because of the poor energy efficiency, very large eductors are not common. There are no obvious 'Grand Coulee' sizes. However spillways of dams, river and coastal defences and large drainage schemes take into account the energy transfer equations that apply.

The biggest sizes that are viable are in the 'multiple kilowatt' band and the smallest can be tiny. As a rule of thumb Liquid/Liquid eductor pumps are in the 25 mm pipe size up to 500 mm, the most common being in the smaller end of this range.

Whether the size is small or large and however the exterior is configured, the heart of the eductor is shown in fig.1.

The taper

Consider again the fire jet and lake. As the eddies swirl away from the point of impact their energy is dissipated and not much gets to the other side. By surrounding the point of impact with a pipe we can direct the lake water to where we want it. If the surrounding pipe is too big eddies still form so a closer fit is required around the entrance. Once the high velocity jet water has transferred its energy the whole body of water needs to be slowed down otherwise the 'friction' losses, as we call them, will be too wasteful. Slowing the water carefully changes its kinetic energy, which is a result of the velocity, into potential energy, which we call head. This is done with a tapered pipe which connects the throat to the pipe work.

Exactly the same considerations apply to the centrifugal pump. The water is booted up to high velocity by the impeller and then run through a relatively small entrance into a tapered pipe. We call this the volute. High velocity water at low pressure is changed to high pressure at low velocity and the pressure drives the water along the pipe against the system head.

The taper controls the rate of deceleration and the eddy losses. It is tolerant of wide variation but 8° inclusive is a popular compromise angle. The wider the angle the shorter the pump but the poorer the efficiency.

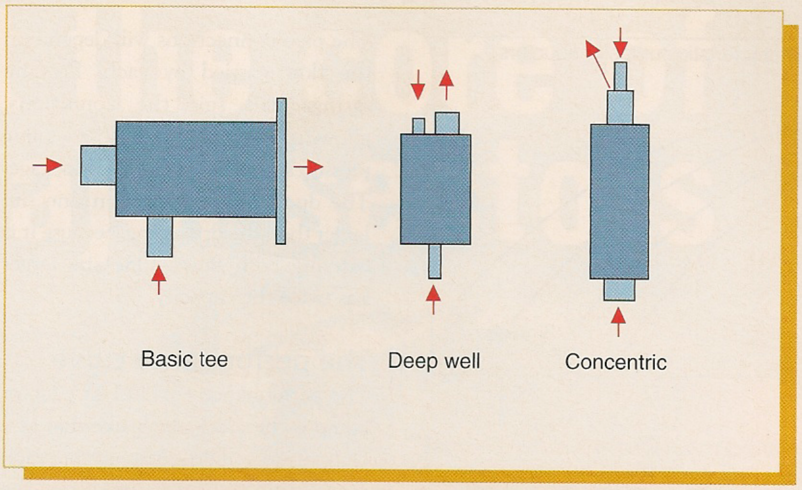

Figure 2. Different configurations are possible.

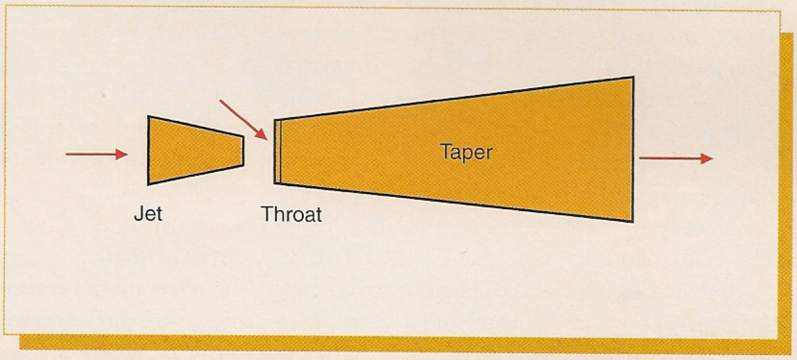

Figure 3. The terminology of eductors.

Here we must pause again to establish the terminology. The term nozzle is sometimes applied to this part. However an eductor pump already has a nozzle, the part that has so far been referred to as the jet. This can confuse. The terms Jet, Throat and Taper as used in Fig. 3 have been found to be easily understood. The term nozzle is eliminated.

The throat

The throat diameter controls the shape of the curve, when related to the jet diameter. A narrow throat gives a high head gain at the cost of flow. Opening up the throat improves the flow entrained and the solid size that can be passed but at the loss of head. It is this jet to throat ratio that is the main design point. Stepanoff, in his excellent treatise on centrifugal and other pumps, covers eductor pumps. He uses the ratio of the areas of the jet and throat which needs further mathematics. I have always

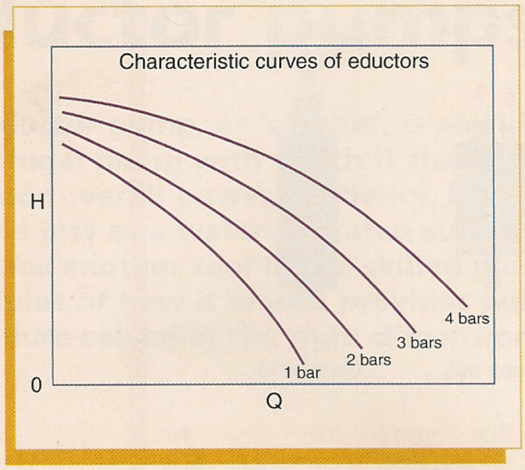

Figure 4. Characteristic curves of eductors.

used the ratio of the diameters which is more practical in engineering. This ratio is designated **R**.

The jet

The jet controls the amount of drive water going into the throat. The higher the pressure at the entrance to the jet the more the flow that goes through it. Table 1 gives the practical results for jets in the commonly used sizes. The pressure must take into account any extra static head which may result from the eductor pump being below (or above) the point of reading the pressure. For instance the jet in a pump in a well with have the benefit of all the static head above it, less any friction losses, at the jet.

The connections

The pipe connections will depend on the flow carried by each. Pressure ratings will suit the conditions, allowing for maximum closed valve pressures in the event of blockage. The discharge pipe is often one size larger than the drive pipe, because it is carrying both flows. One size larger has twice the capacity.

The performance curve

The performance curve of an eductor pump is therefore much like that of a centrifugal pump. Instead of each curve being marked for input rpm the curves are marked for input pressure.

Cavitation curves have the same format

Deep well pumps are presented differently, to suit their mode of use.)

The recovered head.

Fig. 5 gives the relationship between the drive pressure and the recovered head. The recovered head is that pressure measured at discharge end of the taper, just as with any centrifugal pump with which we are all familiar. This is designated H. The recovered head is always less than the drive head. Typically only 30% of the drive pressure is seen at the discharge of the eductor pump.

The entrained flow

The entrained flow is that coming in to the eductor pump from the surroundings. It is the water that you are trying to move. The ratio of the entrained flow to the drive flow is designated Q. The entrained flow is normally less than the drive flow, but 50% to 80% is reasonably achievable. The entrained flow can be greater than the drive flow but at severe loss of head.

Best efficiency point

On Fig. 6 the best efficiency point is indicated by a dot on the curve. This does not take into account the best efficiency point of the drive pump if one is used, as it usually is.

Cavitation

The eductor pump, even one designed for liquid/liquid operation, will pull very high air and water vacuums. However they still cavitate and for high end flows they often need submerging to improve the NPSHa. The vacuum achievable may be high but not necessarily at a high flow rate.

Surface finish and radii

Rounding the throat inlet and bellmouthing the entry are improvements. There was an instance however where a perfectly flat entry improved the efficiency of

TABLE 1. Flow rates in m^3/h, for different jet diameters in mm, at different jet pressures in bars.

Jet dia.	8mm	10mm	12mm	14mm	16mm	18mm	20mm	24mm	30mm	40mm
Drive in bars										
2	3.5	5.5	7.80	10.6	14.1	17.8	22.1	31.9	50.0	89.0
3	4.3	6.8	9.70	13.3	17.4	22.0	27.2	39.3	61.5	109
4	4.9	7.8	11.3	15.4	20.1	25.4	31.4	45.4	71.0	126
5	5.5	8.7	12.6	17.2	22.4	28.4	35.2	50.8	79.4	141
6	6.0	9.5	13.8	18.8	24.6	31.1	38.5	55.6	87.0	155
7	6.5	10.3	14.9	20.3	26.6	33.7	41.6	60.1	94.0	167
8	7.0	11.0	15.9	21.7	28.4	36.0	44.5	64.3	101	179
9	7.4	11.7	16.9	23.0	30.1	38.2	47.2	68.2	107	189
10	7.8	12.3	17.8	24.2	31.7	40.2	49.7	71.8	112	200

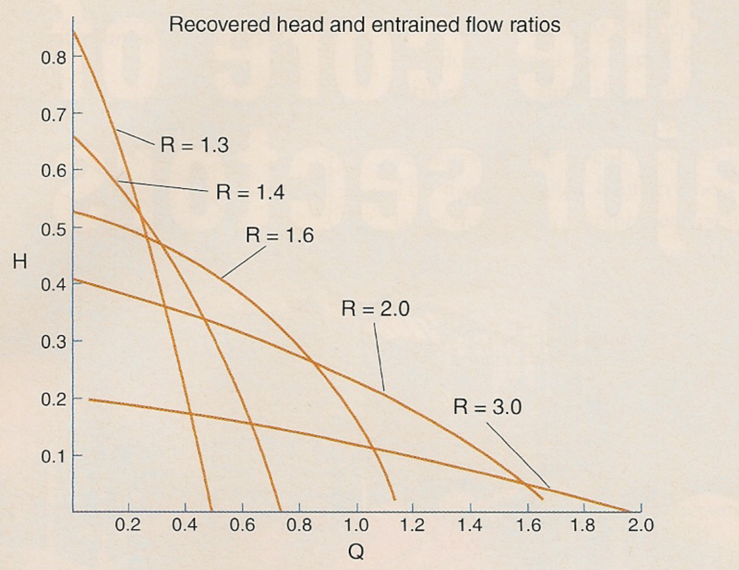

Figure 5. Relationship between recovered head and drive pressure.

Procedure for selecting the dimensions

1. Decide on the flow that you require. (The entrained flow).
2. Select an **R** ratio curve in the middle of Fig. 5 and select a point on that curve near a b.e.p.
3. Check the drive flow required by dividing the flow that you require by the Q factor. The drive flow will normally be greater than the induced flow.
4. Decide on the head you require at the discharge of the eductor pump. (Taking into account the static head and an estimate for the friction at the combined drive and induced flows.)
5. Check the drive head ratio H required at the eductor pump for the point selected above in line 2. Multiply the discharge head from line 4 by this factor to get the drive head. This will be greater than the head from line 4.
6. To get the drive pump pressure add or subtract any static head and line losses. This together with line 3. gives you the size of pressure pump or hydrant characteristics needed to drive the eductor pump.
7. From the drive pressure and flow select a jet size from Table 1. This in turn will give you the throat size from the **R** ratio that you selected in line 2.
8. The throat size establishes the small end of the taper and a taper of 8° included angle brings the diameter up to that of the appropriate pipe connection. It is usually necessary to try different combinations to get an ideal combination to match the availability of drive pumps and to allow for throat diameters large enough to pass solids.
9. The gap between the jet and throat is not critical and a dimension of one throat diameter is suitable on most occasions. Concentricity and alignment should be within standard general engineering practice.
10. When handling denser entrained fluids the flow and head will be reduced in proportion to the specific gravity in a similar manner to a centrifugal pump.
11. When handling viscous materials (9) also applies. This is an energy transfer device like a centrifugal pump.

a gas sampling eductor. Chamfering the exit to the jet reduces breakaway at this point and reduces wear which is due to peripheral recirculation of fine particles at that point. One of the benefits of the eductor pump is however its resistance to abuse and wear. It will soldier on giving reliable pumping when mechanical pumps are in pieces on the workshop floor. A drive pump is still required but this can be made to handle less aggressive drive water or even another other fluid. It can also be more accessible.

Pumping in series and in parallel

Just like a centrifugal pump eductor pumps may be operated in series and in parallel, with similar straightforward precautions. In addition it is common to operate an eductor pump in series with a centrifugal pump. The eductor is used for its remote operation, deep lift etc. and the centrifugal provides the more efficient energy transfer once the water has been brought within range.

Deep well systems are generally like this and the drive water recirculates through the centrifugal pump. Calculations are more involved. A separate high pressure drive pump simplifies the calculations and in the case of slurries reduces the pressure loads on the abrasive handling parts of the system.

General

Whether you are scavenging waste water from under a nuclear power station, or a car plant, getting water from a long way across or down, need an engine driven borehole pump, an eductor pump might just be the best choice. And once installed it will usually be 'Fit and Forget'.

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