PENBERTHY®
a PCC Flow Technologies company

320 Locust Street
Prophetstown, IL 61277-1147
Voice: (815) 537-2311 Ext. 160
Fax: (815) 537-5764
E-Mail: gsanders@penberthy-online.com
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PenTech FAQ # 5 by Gary G. Sanders, Vice President - Engineering

An intuitive approach to jet pumps (eductors, ejectors, inductors, injectors, etc.):

Introduction:
A pump is a device that uses input energy to cause a motion in a fluid. The most familiar pumps are pressure types. They transform input mechanical energy (usually created by an electrical motor) to develop a head (a.k.a. pressure) in a fluid which is expressed as a flow (compressors excepted - flow is sometimes delayed). Examining pump performance curves, it is readily apparent that their ability to transform input energy into a suction head is very limited compared to their ability to generate a 'high' discharge head.

Devices generically known as 'jet pumps/eductors' are kinematic pumps, i.e., their input energy source is a flowing fluid. Examining their performance curves, it is readily apparent that their ability to transform input energy into a discharge head is very limited compared to their ability to generate a suction head. Therefore, they are a complement to pressure pumps.

The basic three principles of operation for jet pumps/eductors (a collective term for many forms of kinematic pumps) are:

1) The definition of a jet is a forceful fluidic discharge from a flow restriction, normally a nozzle.
2) The total system energy is the sum of inlet mass flow and pressure (kinetic and potential energies).
3) Jet pumps are designed to primarily operate on Bernoulli's theorem. It essentially states that in a flowstream as velocity increases, pressure decreases and vice versa.[1]

Common experience of 1 and 2 above is with a garden hose. With no restriction on the end of a hose - a fairly large quantity of water flows but with little exit velocity. Water just kind of falls out of the end of the hose. Placing your thumb as a restriction starts to create jetting action; discharge flow velocity increases, but flow volume is reduced (system energy limited trade off). Essentially a crude nozzle effect has been created. This nozzle effect alone has wide use in fluidic systems, such as spray heads, etc. If the nozzle is ejection ducted (see Fig. 1), a mixing device generally considered to be in the jet pump family is created (e.g., Penberthy's models CTE, TME, NWH).

The Fundamentals:
If a jetting flowstream could be enclosed without retaining any of the flowing fluid, it would be found that the air pressure [wall] around the jetting flowstream would be less than atmospheric pressure which follows Bernoulli's theorem. This is one of the reasons these flowstreams tend to break apart in air.
Of course, it is impossible to enclose a flowstream without collecting fluid; or is it (rhetorical)? [Note: Numerical references (n) are to Fig. 2]. Suppose a large cylinder (2) was sealed (3) to the exterior of an inlet nozzle (1). Then the discharge end of the cylinder (2) was tapered like another larger nozzle (4). The momentum of the inlet nozzle flowstream would force fluid to collect into the second (discharge) nozzle (4) and effectively create a moving fluidic seal. If a port (5) was placed into the cylinder wall and a pressure gauge attached, it would indicate a pressure less than atmospheric (a vacuum) per Bernoulli's theorem. This vacuum would tend to retard the flowstream's exit from the discharge nozzle (4).

If the pressure gauge was removed and the cylinder's port (5) was plumbed into a source of another fluid, the vacuum would create suction. This would cause atmospheric pressure to push a second fluid into the cylinder (2) where it would be mixed with the inlet nozzle flowstream. With the now larger fluid volume, the discharge end (4) fluidic seal would be even more effective. The added suction fluid as it boundary shear mixes with the flowstream would be entrained causing a larger flowing volume but some velocity of the flowstream would be lost.
Thus a suction type pump of limited usefulness has been created. The limit is that essentially all the system energy would be in flow. At the discharge nozzle (4), we are back to the equivalent of our open-ended garden hose example with large flow quantity but little exit velocity. However, we have accomplished a pumping action that has increased the flow volume by adding some quantity of another fluid into the flowstream. This is a classic flow multiplier and defines these devices as true pumps.
For a pump to have broad application, it is necessary for it to generate some discharge pressure so the flowstream can continue down a pipeline. If the discharge nozzle (4) of the cylinder (2), where the fluidic seal was created, was to be constructed with continuing pipe (6) of the same diameter as the discharge nozzle exit, the mixed fluid flowstream would increase its velocity due to the nozzle effect. Think of it as another but less forceful jet with more flow but less velocity than the inlet nozzle (1). After some flow stabilization distance if the inverse of a nozzle (7) (an enlargement of flow diameter, a.k.a. a flow expander or diffuser) is appended it will cause the velocity of the flowstream to decrease while increasing the pressure (Bernoulli again). This increased pressure is now available to provide the 'pushing' pressure to maintain flow into downstream piping.

Terminology:
Doesn't it seem that every technology develops its own set of definitions, a.k.a. buzz words? Jet pumps have most in common with all pumps. Only a few will be discussed here:

Pressure - abbreviated P (often with jet pumps in terms of head h)
Flow (Quantity) - abbreviated Q

Subscripts for these values are standardized to the associated port :

Motive - the inlet port - subscripted m
Suction - the pumped fluid port - subscripted s
Discharge - the downstream outlet port - subscripted d

Thus there are six primary variables associated with jet pump flow characteristics:

P_m, Q_m; P_s often h_s, Q_s; P_d, Q_d

Parts nomenclature: Penberthy chooses to name each part of our standard two piece jet pump by the final action of that part. 1) The inlet port is directly connected to a nozzle and collectively they are called the nozzle. 2) The cylinder where the suction port is located is called the body. The seal off/ pressure recovery area (the second nozzle, the constant area flow section [the parallel] and the inverted nozzle) is called a diffuser. Penberthy combines the body and diffuser into a single piece called the diffuser. Since the internal shape of the pressure recovery area resembles a Venturi flow section, jet pumps are occasionally (but incorrectly) called Venturi pumps. There is a true Venturi pump, one common example is found in carburetor throats and is used to vaporize and mix petrol into the airflow.

Selecting a Jet Pump:
All the energy available for a jet pump to operate is provided by the sum of P_m and Q_m. The internal geometry of the jet pump divides the available energy between suction P_s and Q_s and discharge P_d and Q_d energy. If the suction (pumped) fluid requirement is for a high lift (large head) or a large suction volume load then little energy remains to provide discharge (downstream) pressure. Conversely, if the downstream piping head load is high requiring a high discharge pressure, little energy is reserved for the suction head or volume load.

From a design standpoint, P_m - P_d establishes the residual pressure energy available to be applied to the suction fluid. This residual energy is applied to the sum of the suction head (potential) and suction volume (kinetic). The geometry chosen emphasizes one or the other, higher suction lift or larger suction volume loading. If suction volume is chosen, then discharge loading will change. It should be noted that discharge flow quantity Q_d is the sum of Q_m and Q_s and is not considered a variable. For a fixed geometry, once pressures are defined, then volumetrically either Q_m or Q_s becomes the limiting factor. When one of these is defined, the other flow volume need only be checked against the performance tables/curves for application sufficiency.
Bottom line: All **three pressures and the limiting flow** either Q_m or Q_s are required to define a jet pump's operation.

More Nomenclature:
In other words, the geometry of standard jet pumps is designed and the jet pumps are selected for application based upon the differing pressures at each of the three ports. Thus, Penberthy's model naming convention; e.g.; LL, LM or LH. The first L represents a Liquid operated jet pump. The second letter refers to the relative discharge head load the jet can pump into: L = Low, M = Medium and H = High. If the sum of the suction and discharge loads' energy requirements ever approach the input energy, the jet pump will 'choke', i.e., flow cannot proceed to the discharge port but will divert to the lower pressure suction port (a reason to consider adding a check valve to the suction line).
Standard jet pumps demonstrate fairly low sensitivity to minor perturbations in their discharge head, however, they are sensitive to changes in the suction load. There are several models of Penberthy jet pumps that are designed to minimize this sensitivity, however, the tradeoff is that they become sensitive to discharge head variations (e.g., models UDT, FL).
While discussing naming conventions, the various suffixes to the jet prefix evolved from the use of the jet and the perspective of the user. 1. Eductor - bring something out, from the perspective of the suction fluid. 2. Ejector- more forceful eductor although common usage has evolved it to mean mixing two fluids. 3. Inductor - from the jet's suction port perspective it induces suction flow by vacuum creation. 4. Injector - a specialized kinematic pump that creates discharge pressure higher than the motive pressure.

Sizing a Jet Pump:
Thus far this discussion has emphasized pressure differences at the three ports as the reason jet pumps operate. That is indeed the message - in fact - the fundamental design equation for jet pumps includes ONLY pressure terms. For a given geometry and fixed pressures at each port, one and only one flow condition can exist.
How then can flow quantities be changed? Actually, it is simple. For relatively small changes in flow volume, change the pressures at the various ports (within the operating range of a given jet's geometry). For example, to increase the suction flow, the possibilities are: increase the system energy (P_m), decrease the suction lift (P_s) or decrease the discharge pressure (P_d). The next method is scaling the design; if more flow is required, use a geometrically identical design, just increase the size. At Penberthy, we call this scaling: 'capacity factor'. It only effects flow quantity, not the fundamental jet pump performance. The last option is to change the geometry (i.e., chose a different model).

Boost Pump Application Example:
At the beginning of this FAQ, it was stated that jet pumps are complementary to pressure pumps, now for elaboration. A common method of creating the motive fluid for a jet pump is with a pressure pump, e.g., centrifugal pump.

Conversely, if a jet pump is used with a centrifugal which has a large suction lift requirement, it will compensate for the poor performance of the centrifugal. It also becomes a volume multiplier by using a small fraction of the pressure output of the centrifugal as its motive. This is an example of a jet pump used in the boost pump role and can be found in every shallow well jet pump. These have replaced the older reciprocating PD pumps in nearly every shallow well installation.

General Applications:
Jet pumps are indeed simple devices with no moving parts and may be constructed from almost any rigid formable material.[2] Penberthy has been making jet pumps since 1886 and currently catalogs over 40 models, each designed for a specific type of application.[3] First decide what application you have for a jet pump, for help, consult Penberthy bulletin #1100, Jet Pump Application Guide. Internal geometry fixes the pressure ratio ranges in which a given model of jet pump will operate. These are tabled by Penberthy in bulletins #1200 Pumping Liquids and its addenda #1203 UDT, #1300 Pumping Gases, #1400 Heating Liquids, #1401 Mixing Liquids and its addenda #1410 TME, these bulletins provide the details and sizing tables/curves. If an application requires injection, refer to bulletin #1500, Automatic Injector.

Summary:
For those who have a general understanding of fluid dynamics, this introduction to jet pump technology will be more than adequate. For those with limited understanding of fluid flow, the general selection and sizing of jet pumps is still possible. However, there are some flow complicating factors that need to be considered for optimum performance:

Liquid:
For liquid use, the major problems concern suction pumping of any type, not just jet pumps. Liquids can only be lifted to heights equal to their atmospheric head capability modified by the vapor pressure characteristics of the liquid and suction pipe friction losses. These problems are combined into the concept of NPSH (net positive suction head). These are addressed in Penberthy bulletin #1200. A second consideration is viscosity, generally only a concern if greater than 100 cP, or if the fluid is non-Newtonian.

Gas:
For steam and gas operated or loaded jets, complicating factors include compressibility, condensability of either the load or the motive, super-compressibility, molar fractions of gases, etc. Some of these subjects are briefly addressed, especially in bulletin #1300, however, in depth discussion of these subjects is beyond the scope of this FAQ and even the bulletins. Many excellent texts exist on these subjects.
Another problem is the variety of materials, conditions, pressures and temperatures used with jet pumps (consider ACFM vs. SCFM, etc.). An equalization system called D.A.E. (Dry Air Equivalent) was developed by the Heat Exchange Institute and published in "Standards for Steam Jet Ejectors". An adaptation of this method may be found in bulletin #1300.

Penberthy Jet Product Team Support:
Finally, if there are any questions about an application, please tell us about them. The easiest way is to fill out our Jet Application Sheet. It ensures that required information is supplied and reviewed (remember three pressures and the limiting flow). You may 'hot key' to a Jet Application Sheet if you are visiting Penberthy's web site at www.penberthy-online.com or paper Jet Application Sheets are available from any Penberthy distributor. Our staff applications personnel will review your application sheet for feasibility.

Aside:
In today's world of information overload: quick, concise and condensed is the ideal. For this FAQ, I combined seventeen different recurring questions about jet pumps. Although I could have addressed each question in a separate FAQ, the result would have been disjointed. Therefore, I decided to attempt as much as possible to form a cohesive answer to all seventeen questions into a single FAQ. I suspect this will be the longest PenTech FAQ I will write. For those who find its length objectionable, I apologize. My goal is to average two pages or less per FAQ.

Footnotes:

1. For the purists: Neglecting friction, including turbulent flow frictional losses, Swiss scientist (1700 -1782) Daniel Bernoulli's theorem is a restatement of the law of conservation of energy. Within a given isogravitational, irrotational, non-viscous flowstream, mass flow [kinetic energy ($\rho v^2/2$)] and pressure [potential energy ($_x\nabla DP$)] equals the system energy. It remains a constant throughout the system.

   Sort of like the flight of an aircraft at constant throttle setting - altitude [potential] and airspeed [kinetic (velocity)] are the system energy. They may be interchanged: nose down into a dive, airspeed increases but altitude is lost; nose up into a climb, altitude is gained but airspeed decreases.

2. Some jet pump advantages compared to pressure pumps:

Simple design	No moving parts	Self priming	Intimate mixing
No lubrication	Easy installation	Low maintenance	Low purchase cost
Low installation cost	Intrinsically safe	Easily remoteable	Light weight
No packing glands or seals to leak		Do not require electricity	Broad viscosity range
Some models 'pump' bulk solids or particulates		Operates in extreme temperatures	

   Cavitation effects are minimal
   Can pump intermittently or 'dry' without damage to the pump
   If proper materials of construction are used, can operate in any corrosive environment
   Sizes (measured at discharge port) = 1/2" NPS to ??? (Penberthy's largest design to date is 84" NPS)
   Equivalent sizes are available in flanged (ANSI, 3A, DIN, JIS, etc.) or threaded (NPT, BSP, ISO, etc.)
   Custom designs are available at reasonable costs

3. Some common applications:

   Pumping :

Gases	Liquids	Slurries	Solids transport
Creating vacuums	Exhausting	Evacuating	Aeration (eliminates misting)
Priming other pumps	Foam reduction	Offloading (ships, railcars, tanker trucks, etc.)	

   Boost pump for high suction head pressure pump
   Draining (tanks, sumps, swimming pools, water beds, etc.)
   Self contained, non-electrical back-up boiler feed water pump
   (or primary - consider a steam locomotive, traction engine, etc.)

   Mixing:

Proportional	In line	In tank	Blending
Create flocculate	Maintain emulsions		Eliminate stratification
Create slurry	Maintain suspensions		Diluting

   Tank sweeping (bottoms, corners: where mechanical agitators cannot reach)

   Heating:

In line	In tank	In vessel	While mixing

Combinations of above uses applied simultaneously, e.g.,
using a steam motive for in tank mixing yields heating + mixing + dilution; etc., etc., …… ∞.

An intuitive approach to jet pumps/eductors - Addenda

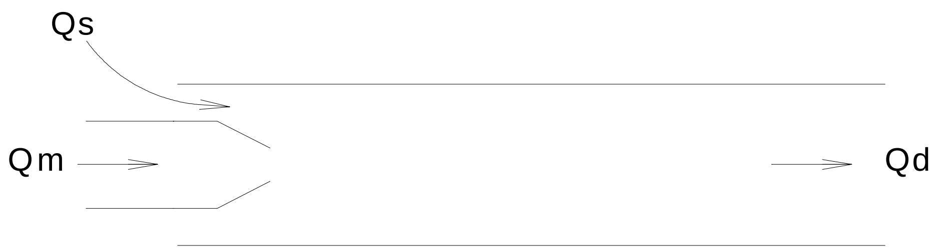

Figure 1

Example of an ejection ducted nozzle. Its function is similar to a ducted fan or propeller.

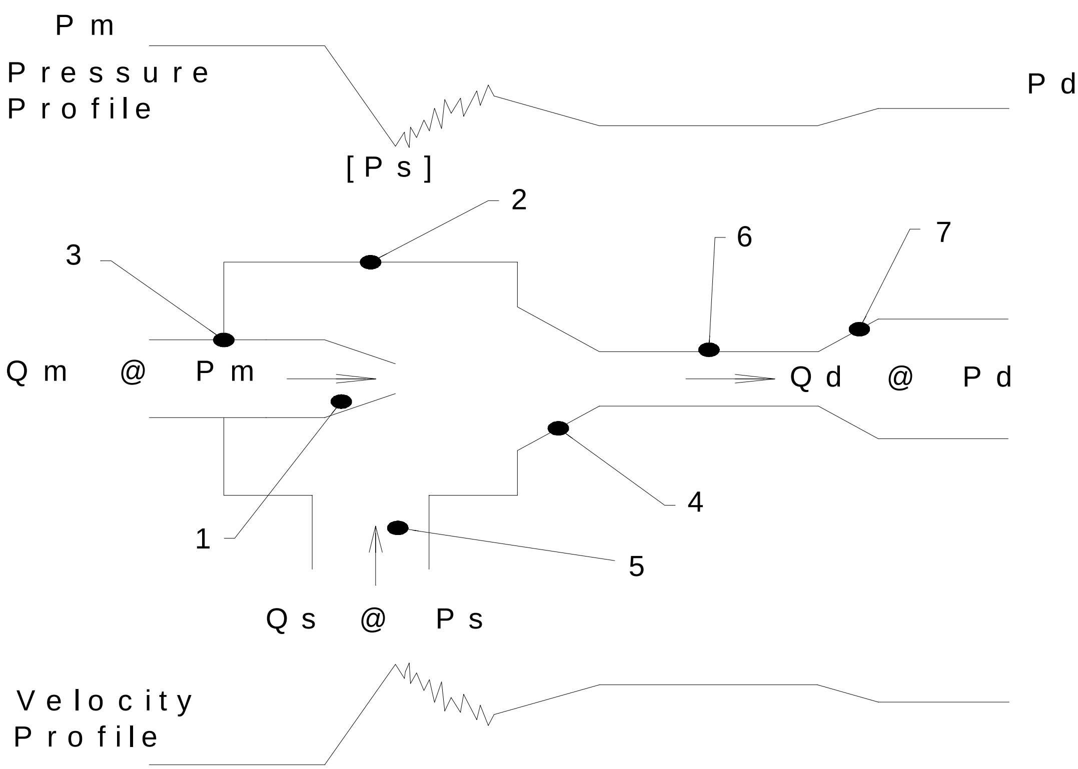

Figure 2

Line drawing of the functional geometry of a standard jet pump plus pressure and velocity profiles. The profiles are illustrative of relative values for low suction volume pumping, no absolutes should be inferred. The dithered areas are where the motive and suction flowstreams converge. [P_s] on the pressure profile lies somewhere in the dither, depending on the volume load.
Interestingly, the kinematic profiles tend to approximate the geometrical profile of the device.