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Ejectors and jet pumps
Design and performance for incompressible liquid flow

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THE PREPARATION OF THIS DATA ITEM

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The Internal Flow Panel, which took over the work on internal flow previously monitored by the Fluid Mechanics Steering Group, first met in September 1979 and has the co-operation of many engineers and scientists in industry, research establishments and universities from whom much assistance and information is being received.

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EJECTORS AND JET PUMPS - DESIGN AND PERFORMANCE FOR INCOMPRESSIBLE LIQUID FLOW

CONTENTS

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1. NOTATION AND UNITS

		Units	
		SI	*British*
A	cross-sectional area	m^2	ft^2
a, b, c	coefficients in quadratic expression for M_0	–	–
C	fluid density ratio, secondary fluid density/primary fluid density, $C = \rho_s/\rho_p$	–	–
C_{pr}	diffuser static-pressure recovery coefficient (see Equation (B2.5))	–	–
d	diameter of primary nozzle exit	m	ft
D	diameter of mixing chamber	m	ft
f	friction factor, defined from head loss $= 4f(L/D)(V^2/2g)$	–	–
g	acceleration due to gravity	m/s^2	ft/s^2
H	total head	m	ft
K	component loss coefficient	–	–
L	length of mixing chamber	m	ft
l	characteristic length	m	ft
M	volume flow ratio, secondary flow rate/primary flow rate, $M = Q_s/Q_p$	–	–
M_0	value of M when $N = 0$	–	–
N	pressure ratio, secondary flow pressure rise/primary flow pressure drop, $N = (P_5 - P_2)/(P_1 - P_5)$	–	–
N_0	value of N when $M = 0$	–	–
N'	alternative pressure ratio, secondary flow pressure rise/primary-secondary pressure difference, $N' = (P_5 - P_2)/(P_1 - P_2)$	–	–

For footnotes see end of Notation Section.

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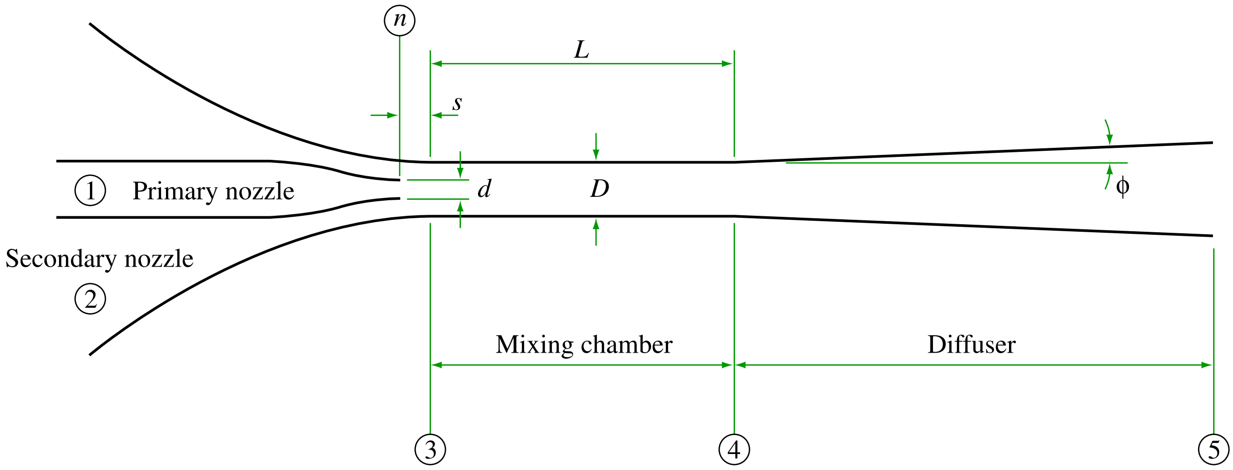
P	total pressure	Pa (N/m^2)	lbf/ft^2
p	static pressure	Pa (N/m^2)	lbf/ft^2
Q	volume flow rate	m^3/s	ft^3/s
R	area ratio, A_n/A_m	–	–
Re	Reynolds number, $Re = Vl/\nu$	–	–
s	distance from primary nozzle exit to mixing chamber entrance	m	ft
V	velocity	m/s	ft/s
ε	effective roughness height of mixing chamber surface	m	ft
η	jet pump efficiency, $\eta = M \times N$	–	–
ϕ	diffuser half angle	deg	deg
ν	kinematic viscosity	m^2/s	ft^2/s
ρ	density	kg/m^3	*slug/ft^3
σ	cavitation number, $\sigma = (P_2 - p_v)/(½\rho_s V^2{}_{3c})$	–	–

* 1 = slug = 32.174 lb (pound mass).

Subscripts

1, 2, 3, 4, 5	planes within the ejector, as defined in Sketch 1.1
d	diffuser
c	cavitation-limited flow value
m	mixing chamber
n	primary nozzle exit
p	primary or driving flow
ref	reference or datum value
s	secondary or induced flow
v	vapour



Sketch 1.1 Jet pump configuration and reference planes

2. INTRODUCTION

This Item is concerned with the design and performance of ejectors and jet pumps. Such devices are characterised by the use of the kinetic energy of one fluid stream (the primary flow) to drive a second fluid stream (the secondary flow) by direct mixing. The fluids may be gases or liquids and the secondary stream is not necessarily the same fluid as the primary. For some applications the secondary stream, and the primary stream also, may contain solid particles. The design parameters, requirements and methods vary considerably, depending on whether the working fluids are gases, liquids, solids-in-fluids or combinations of these, and each type is therefore considered in a separate Data Item.

The terms “ejector” and “jet pump” are alternative names for the same device and the term “injector” is also used.

2.1 Purpose and Scope of this Item

This Data Item provides information for design and performance evaluation of ejectors and jet pumps in which both working fluids are liquids. A technique for the optimum design of a jet pump or ejector is presented; the method is based on the equations of continuity and momentum conservation and includes empirical coefficients that allow for losses in the different components. The performance of an ejector or jet pump of given dimensions may be determined from an appropriate performance characteristic curve, which fully describes the operation of the device. A comprehensive series of such curves is presented, based on a large number of empirical and analytical data.

2.2 Layout of this Item

Section 3 of this Item discusses briefly some applications of ejectors and jet pumps.

Section 4 describes the principles of ejector operation and defines the different components. These may vary considerably with application and Section 4 considers some of the possible configurations.

Section 5 describes a design method which will determine the on-design operating conditions and optimum dimensions for an ejector or jet pump when the primary and secondary working fluids are both liquids. The method is suitable for primary and secondary fluids of equal or differing densities. Mechanical design aspects are considered in Section 5.5.

Section 6 describes a method by which the performance of an existing ejector or jet pump may be evaluated. Performance charts are presented for the case when the working fluids are of equal density together with corrections allowing for differing densities.

Section 7 describes, briefly, more complicated ejector designs, such as multi-nozzle or annular ejectors or multi-stage configurations, and considers their advantages in certain situations.

Section 8 discusses the problem of cavitation and includes a definition for cavitation index. The index characterises the conditions under which cavitation occurs and may be used to predict the onset of this phenomenon. Methods for improving cavitation performance are also described.

Section 9 presents worked examples showing the application of both the design and the performance prediction methods.

Section 10 lists all the sources of information used in compiling this Data Item and includes further sources of reference which may be helpful to the engineer.

Appendix A contains a glossary of terms used in describing jet pump components, design parameters and performance.

Appendix B presents a detailed theoretical analysis of the flow through an ejector, based on one-dimensional flow representations of mass and momentum conservation, and includes the development of equations used to describe efficiency and the onset of cavitation.

Appendix C presents flow charts outlining the design and performance prediction procedures.

3. APPLICATIONS OF LIQUID EJECTORS AND JET PUMPS

Ejectors and jet pumps are used in a wide range of engineering fields, as is illustrated by the following examples. Their particular advantage lies in their flexibility and simplicity of operation and in the low level of maintenance required. The ejector is especially useful where a source of high energy fluid is available as the by-product of some other process, although this is by no means an essential requirement.

Aeration

A jet pump may be connected across a centrifugal pump to aerate the fluid. Examples of this type of application can be found in an abattoir, or in a coal mine where the jet pump acts on unoxygenated mine water to oxidise dissolved iron compounds and secure their precipitation before discharge.

Booster Pumping

A liquid jet pump may be used to boost the pressure and supply in a pipe network system. Water supplied to a reservoir under pressure can be utilised to act as the driving flow of a jet pump which is installed at the outlet from the reservoir. Similarly, the flow rate of a high pressure water supply can be boosted with ground water by incorporating a jet pump in the pipeline.

Cleaning and Reducing Turbidity

Tests have been performed on the viability of a jet pump used to pump water to or from an estuary. This is intended to reduce or prevent growth of algae and improve the water quality. If successful, the pump could obviate the need to construct a canal opening to the sea.

Deep Well Pumping

When a liquid such as oil or water has to be raised from deep wells, the suction lift may exceed the absolute vapour pressure of the liquid. This makes it necessary to lower the pumping unit into the well shaft if a centrifugal pump alone is used. An alternative procedure is to use a jet pump in combination with a centrifugal pump; the centrifugal pump is mounted at ground level and provides the driving head and primary flow for the jet pump placed in the well below. Mechanical advantages are that there are no moving parts in the well, very little maintenance of the jet pump is necessary, and the centrifugal pump and motor may be placed at any convenient point. Hydraulic advantages are that the jet pump-centrifugal pump combination gives a steep head-mass flow operating characteristic with a higher operating head than that of a centrifugal pump alone, and a non-overloading brake horsepower curve (Derivation 2).

A similar type of application is the extraction of slops, grit, oil, water, *etc*. from cargo holds in ships, or similar situations where space can be highly restricted. Vertical suction lifts of 30 m have been achieved with deck-mounted units, where there was no room for the pump to be lowered into the hold, by allowing air to enter the suction orifice with the liquid.

Domestic Water Supply

The simplicity of construction and maintenance of the jet pump has led to its wide-spread use, in conjunction with a centrifugal pump, in shallow-well pumping for farm and domestic water supplies (particularly in the USA and Canada). The centrifugal pump and the jet pump are located together at ground level. The system exhibits an almost constant power characteristic, which makes it extremely versatile.

Dredging

In this application an inclined or vertical dredging ladder comprising at least driving and discharge pipes is supported from a floating pontoon or hull. The jet pump is at the lower end and may be immersed in the deposit being dredged. It is often convenient to use water jets for disintegration or fluidisation of the bottom material, the supply being derived from a separate pump or, if the optimum pressure is compatible, from the jet pump primary water supply.

The use of a jet pump avoids having solid materials pass through the driving centrifugal pump so the sediment cannot clog or erode the pump impeller and, although the solids may pass through the jet pump, the wear rate is low. The motive pump set is able to run at constant speed and constant load. (See Reference 33.)

The system is designed so that the jet pump characteristic and the pipeline head characteristic intersect so as to give a stable flow; in fact, jet pump dredges can be so stable in operation that they do not require supervision.

Hydro-electric Schemes

Ejectors may be used to suppress tail-water back-pressure when flood conditions prevail or to increase the effective head available for power production when relatively high water levels are required downstream, for navigational or irrigation purposes. The ejector may be incorporated with reaction or impulse turbines, as well as with tidal power units.

Lubrication Systems

The simplicity and light weight of the jet pump make it attractive for use in lubrication systems, particularly for aircraft engines. A major advantage is the elimination of the mechanical drive train necessary for conventional pumps. However, in this application cavitation limitations may cause problems at high operating altitudes of the aircraft.

Mixing

During the momentum transfer process in the mixing chamber, almost complete mixing takes place. Thus the jet pump has application in mixing chemical solutions, making gels and suspensions or diluting noxious liquids.

Multi-pressure Systems

In facilities such as dry docks and laboratories where both high and low pressure systems are required, with low and high discharges respectively, it can be cheaper to operate a single set of pumps. In this application the jet pump may be used in combination with a centrifugal pump, as a slightly changing head can vary demand on the jet pump unit while the centrifugal pump can operate against a fixed discharge at its best efficiency point. A jet pump may also be used as a pressure limiting device in a multi-pressure system.

Nuclear Industry

Jet pumps are frequently used in the nuclear industry, both for the transport of radioactive materials, slurries, *etc*. and to produce a vacuum. Jet pumps have also been used as recirculation devices to circulate coolant in a reactor core. Their use can reduce the number of recirculation loops, saving pipe, valve, pump and motor costs and also eliminating equipment susceptible to breakdown. A major advantage of jet pumps in all nuclear applications is their reliability and the low level of maintenance required.

Priming Devices

Siphons can be swiftly primed by means of ejectors; there is no necessity to use foot-valves and the continuous operation of the pump throughout the siphoning process can alleviate problems of vapour accumulation or air leaks in sub-atmospheric conditions. Alternatively, a jet pump may be used by itself as a priming device.

Pumping Sludges

Jet pumps are used for the removal of oil sludge on board ships and tank de-sludging in the petrochemical industries and for the pumping of mud on oil rigs, where mud is also used as the primary fluid. Ejectors may also be used for the pumping of primary-digested sewage to tanks and ponds, having the advantages that the rate of disposal of the fibrous material is high and that the sewage tends to lose its non-Newtonian properties after passing through the jet pump.

Solids Transport

Jet pumps are widely used as boosters in pipelines through which solids as widely varied as coal, sand, ash, radioactive materials and foodstuffs are transported. The solids may pass through the jet pump or may be intercepted first; this latter configuration is rather more complex but avoids the friction losses and abrasion problems incurred when the solids do pass through. The turbulence to which the solids are subjected in the mixing chamber may be used to advantage in the scrubbing of minerals or sand. Conversely, in the transport of foodstuffs it is important that little damage is incurred. An annular jet pump is suitable for handling delicate products, since the solids mainly pass up the centre of the jet pump and are kept away from the mixing chamber walls.

Throttling Devices

A jet pump may be used as a throttling device between two systems or for surge damping.

Thrust Augmenters

The thrust of a jet may be augmented by the use of a mixing chamber with a driving jet; this is comparable to other methods of jet propulsion, though less common with liquid than with gas ejectors. Such a device has been used for controlling ships and can avoid the need for tugs in dynamic positioning.

Trench Cutting

Jet pumps are used in offshore applications for cutting trenches required for burying pipelines and cables.