

EXPERIMENTAL ANALYSIS OF A TWO-PHASE EJECTOR PUMP USED IN VACUUM DESALINATION SYSTEM FOR LOW PRESSURE CREATION

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Abstract- Utilization of renewable energy needs no emphasis. One such form of energies is ocean energy. The importance of desalination is increasing day by day, as there is demand of potable water with increasing population, industrialization and limited natural resources for fresh water. In view of the above, a two-phase (water-air) ejector pump assisted low pressure desalination system has been analyzed. This system utilizing ocean thermal energy is of rather greater importance for potable water supply in countries like Oman without sufficient natural water source. In this paper the performance of the ejector pump is carried out to meet out the low-pressure requirement of desalination system has been analyzed experimentally.

Index Terms-Desalination, two-phase, low-pressure, ejector, evaporation.

I. INTRODUCTION

Due to increased potable water demand across the world, brackish/seawater desalination is becoming the technology of choice in increasing water supplies in many parts of world. Though many desalination methods have been introduced many years ago, there are still areas around the globe suffering from potable water shortages. Due to the huge quantities of thermal energy and high quality electricity requirements for water purification, the desalination industry depends on renewable energy sources and waste energy sources from power plants, geothermal, wind and tidal energy sources. Water scarcity in different parts of the country have left many of us wondering if Oman is moving fast enough to prevent a crisis. Studies specify that there is, at least, a shortage of over 325 million cubic meters of water each year in Oman between replenishment and demand. With an estimated total population of 3.83 million and a renewable recharge of water one billion cubic meters per year, just 416 cubic meters of water is available per person per each year. This places Oman well within a sector defined as being water scare. In the view above, a laboratory scale two-phase ejector pump assisted low temperature desalination system utilizing ocean thermal gradient is developed. The creation of low pressure required for the desalination system is by two-phase ejector pump, expansion of brackish water reducing its pressure to a low value, evaporation of brackish water at reduced pressure using heat from the surface sea water and condensation of vapour at that pressure using cold water from the ocean. The heart of the desalination system is two-phase ejector, which creates and maintains the low pressure inside the chamber of the system. So, the two-phase jet pump was experimented to give maximum low pressure, as evaporation of brackish water depends on low

pressure. The ejector pump was tested for its different orifice spacing (S) (space between supply tube and mixing chamber entry) starting from 28 to 48 mm and the maximum low pressure was achieved at $S = 33$ mm.

II. REVIEW OF LITERATURE

Thermally driven desalination systems have established greater attention as the predictable world energy shortage can easily be tackled and the abundantly available renewable energy such as ocean energy, solar energy, geo thermal energy etc. and waste heat from power plants can effectively be utilized. The process of vacuum desalination was reported by Low and Tay [1]. This technique takes advantage of the drop in boiling point of seawater if the saturation pressure is reduced. Using waste heat from a steam turbine, a laboratory scale study was conducted to investigate the feasibility of using a vacuum desalination process for water supply by Tay et. al. [2]. Sergio Mussati et. al [3] discussed a methodology for optimization of a system configuration for dual-purpose desalination plants working under low pressure. Shivayyanamath and Tewari [4] discussed about the dynamic simulation for the analysis of start-up characteristics of Multi-Stage Flash (MSF) desalination plants (which are working based on the principle of vacuum desalination) using a mathematical modeling. A simulation model of the desalination system has been developed by Avraham Kudish, et.al [5] and validated by inter-comparison with experimental measurements on such a system. The experiments were conducted by Maheswari et.al [6] in a 5 hp diesel engine to analyze the performance of the submerged horizontal tube straight pass evaporator (SHTE) under various load conditions. It was evident that 3.0 lph of saline water could be

desalinated from the engine exhaust gas, without affecting the performance of the engine. Desalination yield has been augmented with two stage HDH integrated cooling plant. A humidification – dehumidification pilot desalination plant was developed and analyzed by Chiranjeevi et. Al [7] with experimental and simulation studies. In their studies, nearly 1.5 lph of desalinated water is resulted at $15 \text{ m}^3/\text{h}$ of air.

III. PRINCIPLE OF OPERATION

A schematic representation of two phase ejector pump (sometimes it is called as jet pump) is shown in Fig. 1. The jet pump for this investigation consists the following elements: the orifice, suction chamber, orifice spacing (S), the secondary inlet, mixing tube and diffuser. Primary fluid, i.e., brackish/seawater is pressurized by an independent source and leaves the orifice at high velocity. This high

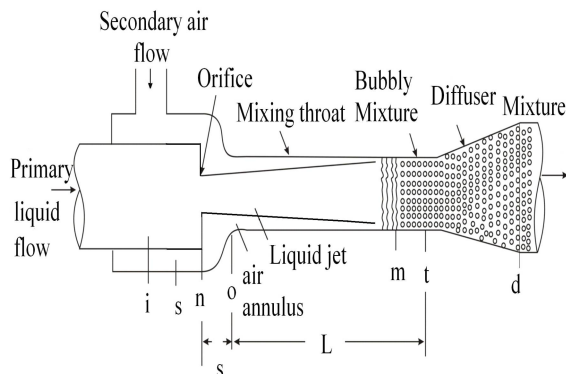


Fig. 1 Schematic diagram of two-phase ejector

velocity jet sucks secondary fluid (air) in the direction of the driving seawater. The acceleration of the particles of the surrounding (suction) fluid is achieved by impact of particles from the driving orifice seawater in the mixing tube. Finally kinetic energy is converted to pressure rise of mixed fluid takes place in the diffuser. The ejector pump is designed using equations of continuity, momentum and energy. Table I gives the design details of ejector pump. The test set-up created for this purpose was a continuous circulation, open loop system. Fig. 2 shows the schematic diagram of the test rig. Seawater from an open tank is pressurized by a multi stage horizontal axis centrifugal pump having a variable frequency drive (VFD) and the high pressure water is supplied to ejector pump orifice as the motive fluid. Orifice produces high velocity jet, creates vacuum in the suction chamber of the ejector pump, hence suction of secondary air from the desalination system chamber takes place. The water and air mix thoroughly in the mixing tube. The diffuser converts energy of this mixture partially from kinetic to pressure. Then the mixture returns to water tank through pipe line. Due to low pressure inside the chamber of the desalination system, the seawater to be desalinated already in the

chamber start evaporates; the water vapour from the bottom of the chamber is condensed at the top of the chamber by a seawater cooled condenser. The seawater from the deep sea is circulated through the condenser tubes. The condensate is the fresh water was collected frequently. The chamber low pressure created by the two-phase ejector pump with respect to time for four orifice spacing (S). Orifice spacing and primary flow rates were varied for this study during experimentation.

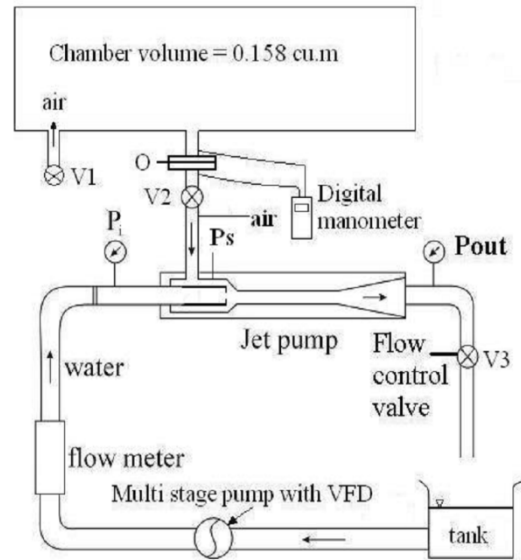


Fig. 2 Schematic of the ejector/jet pump experimental set-up for vacuum creation

I DESIGN DETAILS OF EJECTOR

Part name	Dimension
Orifice diameter	7 mm
Suction chamber diameter	50 mm
Mixing tube diameter	10 mm
Length of the mixing tube	262 mm
Distance between orifice exit and mixing tube entrance (S)	28 mm
Length of the diffuser	135 mm
Length of ejector pump	800 mm

The geometrical dimensions and the input parameters of various combination were used are presented in Table II. Test runs were conducted by closing flow control valve of the ejector pump in discrete steps. Hence flow ratio ($Q_{\text{AIR}}/Q_{\text{SEAWATER}}$) was varied by keeping primary water flow rate is constant. The valves V1 and V2 were always opened for all operating condition to find out optimum conditions. This procedure was followed at four orifice spacings. To create chamber low pressure the valve V1 was closed and valve V2 was left open. Other parameters like diffuser length, diffuser angle, mixing tube (mixing throat) diameter were held constant. Orifice spacing (S) and primary discharges (Q_{SEAWATER}) were varied during experimentation.

II INPUT PARAMETERS

D_o (mm)	5	7	9
R	0.25	0.49	0.81
S (mm)	28, 31, 33, 38	28, 33, 38, 40	28, 33, 40, 42
Q_{seawater} (lps)	0.278, 0.361, 0.417, 0.472, 0.556	0.278, 0.361, 0.417, 0.472, 0.556	0.278, 0.361, 0.417, 0.472, 0.556

IV. INSTRUMENTATION AND CALIBRATION OF INSTRUMENTS

The primary water flow rate was measured with a wheel type flow meter. Secondary air flow was measured with an orifice meter which was connected to digital manometer.

Three measured by precision digital compound gauges. Vacuum created in flash chamber with respect to time was measured by a pressure transducer which was connected to data logger. Pressure gauge, pressure transducer, flow meter and orifice meter were calibrated adopting standard procedures. Instruments/sensors used for measurement of parameters, their range and accuracies are shown in Table III. The orifice meter's upstream and downstream pressure points were connected to digital manometer. Two pressure transducers were connected in parallel with these pressure points for calibration of digital manometer. Digital compound gauges were calibrated with the help of pressure transducers connected in parallel which was connected to data logger. Pressure gauge which was used to measure the primary water pressure was calibrated with dead weight tester. The primary water flow rate was measured by collecting water manually and measuring it.

V. RESULTS AND DISCUSSION

The Fig. 3 shows the variation of chamber pressure with time for four different orifice optimum spacings and for orifice diameter 5 mm. From the Fig. 3, it was found the chamber pressure decreases when time increases. This experiment was conducted by opening valve V2 fully and closing valve V1. The minimum chamber with respect to time and time taken to reach 0.015 bar higher than the minimum pressure defines T_{CRITICAL} were found.

Fig. 4 shows the minimum chamber pressure created by ejector and the time t_{critical} for four orifice spacings. The ejector gives the maximum efficiency at $S = 33$ mm the pumping capability (evacuating capability) of the ejector is high (Fig. 3).

III INSTRUMENTATION AND RANGE OF ACCURACIES

Measurement parameters	Instruments used	Range	Accuracy
Chamber vacuum	Pressure transducer	0 – 3 bar (abs)	$\pm 0.5\%$ F.S.
Secondary air flow rate	Digital manometer	0 – 35 kPa (abs)	$\pm 0.1\%$ F.S.
Vacuum pressure of ejector pump	Digital gauge	0 – 4 bar (abs)	$\pm 0.1\%$ F.S.
Outlet pressure of ejector pump	Digital gauge	0 – 4 bar (abs)	$\pm 0.1\%$ F.S.
Primary water flow rate	Wheel type flow meter	0 – 10000 lph	± 1 lph
Primary water pressure	Bourdon pressure gauge	0 – 25 bar	$\pm 2\%$ of F.S.

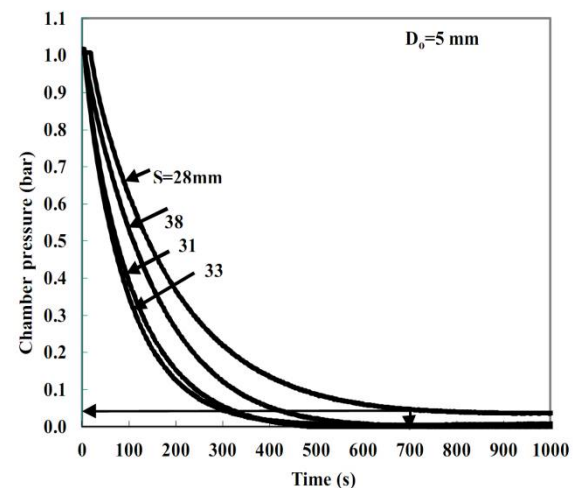


Fig. 3 Variation of chamber pressure with time for four optimum S ($D_o = 5$ mm)

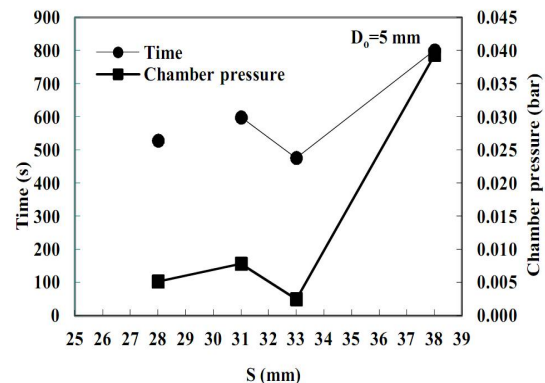


Fig. 4 Effect of orifice spacing S on time and chamber pressure for four orifice spacings at optimum conditions ($D_o = 5$ mm)

At $S = 33$ mm, the minimum chamber pressure of 0.002 bar is obtained at 476 sec. So, from the above results, it may be concluded that the best orifice spacing is $S = 33$ mm, since maximum chamber pressure i.e., minimum vacuum is obtained in reasonably lesser time.

The experiments have been conducted for other orifice diameters $D_o = 7$ mm, 9 mm and for four different

orifice spacings (S). The minimum chamber pressure corresponding to the time was taken and critical time, chamber pressure were plotted against orifice spacings. The results are shown in Figs 5 and 6. From the Fig. 5, it was found the chamber pressure decreases when time increases. The minimum chamber with respect to time and time taken to reach 0.015 bar higher than the minimum pressure defines $t_{critical}$ were found. From Fig. 6, the ejector gives maximum efficiency at $S = 38$ mm the pumping capability (evacuating capability) of the ejector is high.

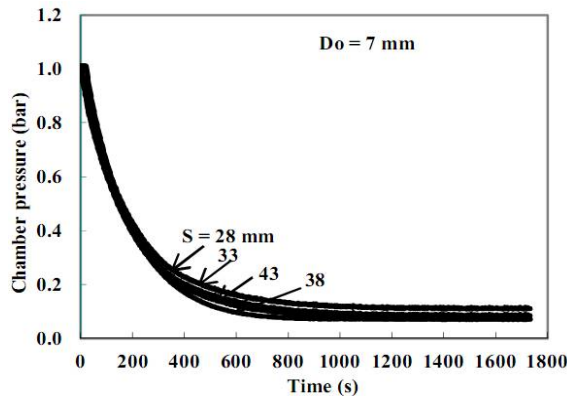


Fig. 5 Variation of chamber pressure with time for four optimum S ($D_o = 7$ mm)

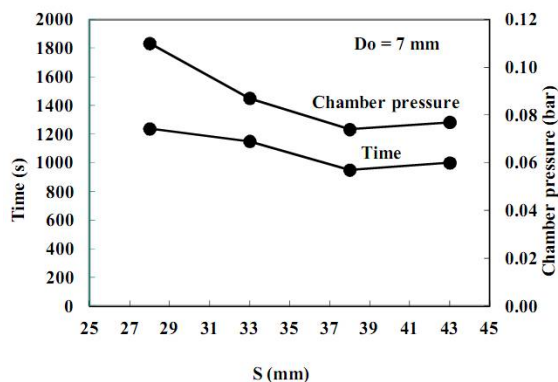


Fig. 6 Effect of orifice spacing S on time and chamber pressure for four orifice spacings at optimum conditions ($D_o = 7$ mm)

By comparing Fig. 4 and 5, it has been concluded that the ejector pump with $D_o = 5$ mm, $S = 33$ mm was found to be higher efficiency and good in performance and this combination of the ejector is recommended for the desalination system for maximum low pressure creation and efficient working.

CONCLUSIONS

An ejector pump assisted desalination system was designed and developed for converting seawater to fresh water. The ejector pump which is the heart of the desalination system was analyzed experimentally for maximum vacuum creation. Various orifice diameters

of the ejector pump was analyzed with different orifice spacing and finally inferred that the ejector pump with $D_o = 5$ mm, $S = 33$ mm was found good in performance.

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Nomenclature

D - diameter, m
 P - Pressure, Pa
 Q - discharge, litres per sec
 R - area ratio = Mixing throat area/Orifice area
 S - orifice spacing, mm

Subscripts

o - orifice

Refer Fig.1 and 2

d - diffuser
 i - inlet
 m - mixing of two fluids
 n - nozzle/orifice
 s - suction
 t - throat
 L - mixing throat length
 V - Valve
 VFD- Variable frequency drive

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