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PRELIMINARY INVESTIGATION ON THE EFFECTS OF SHOCKWAVES ON WATER SAMPLES USING A PORTABLE SEMI-AUTOMATIC SHOCKTUBE

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ABSTRACT

The propagation of shock waves through any media results in an instantaneous increase in pressure and temperature behind the shockwave. The scope of utilizing this sudden rise in pressure and temperature in new industrial, biological and commercial areas has been explored and the opportunities are tremendous. This paper presents the design and testing of a portable semi-automatic shock tube on water samples mixed with salt. The preliminary analysis shows encouraging results as the salinity of water samples were reduced up to 5% when bombarded with 250 shocks generated using a pressure ratio of 2. 5. Paper used for normal printing is used as the diaphragm to generate the shocks. The impact of shocks of much higher intensity obtained using different diaphragms will lead to more reduction in the salinity of the sea water, thus leading to production of potable water from saline water, which is the need of the hour.

INTRODUCTION

A sound wave is a naturally weak wave that causes minor changes in the properties of the fluid along which it travels. The speed of sound is found to be more in solids, quite lesser in liquids and a minimum in gases. The sound waves travel through a gas by the numerous collisions of the molecules in it and these disturbances usually travel with the speed of sound. Moving shock waves are generated when the disturbances due to Collison of molecules is forced through the gas at a speed greater than the speed of sound [1]. Shock tube is a simple device that is used to generate a shock wave in a controlled environment. The driver section in which a gas is compressed to high pressure is separated from the driven section maintained at low pressure or atmospheric pressure by a diaphragm. When the pressure in the driver side exceeds the preset limit, the diaphragm ruptures and causes a shock wave to move along the length of the driven section. These shock waves can be utilized for emerging industrial, commercial, defense, agriculture and home appliance applications like juice extraction, rejuvenating depleted bore wells artificial insemination, treating brain injuries etc.,

LITERATURE BACKGROUND

For the past few years, scientists have been exploring possible ways to effectively use the shock waves for the betterment of humanity and it is encouraging to see the applications expanding in the recent times. Some of the proven researches with positive outcomes reported in the literature are given below.

Jourdan et.al developed an experimental set-up to investigate the attenuation of a shockwave propagating through a well-characterized cloud of water droplets in a vertical shock tube with different shockwave Mach numbers and droplet diameters. The need for improved quality of visualization and precision of pressure measurements was pointed out in addition to the necessity of improving the physical model [2].

Reddy has developed a simple hand-operated and miniature shock tube, capable of producing shockwaves of Mach 2. The research outlines the design principles and performance capabilities of this mini shock tube, which is more versatile than a traditional compression-driven and blast-driven shock tubes. It is also the first device to produce supersonic flows of sustained duration using human energy, which can generate a Mach more than 1.5. This prototype is a simplified and miniature version of the free-piston driven shock tube (FPST) also known as Reddy's tube which was developed earlier. This miniaturized shock tube has a cylindrical compression tube of length 60 mm length, internal diameter 12.8 mm and a wall thickness of 1 mm [3].

The works of Ulises et.al shows the influence of shock waves on the viability of two strains of bacteria in solution and to verify the impact of shock waves on the microorganisms. It is seen that the lithotripter shock waves do not have significant bacterial effect during shockwave lithotripsy, however bacteria inactivation may be achieved using tandem shock waves [4].

Daosheng Deng et.al performed studies on water Purification by Shock Electro dialysis to filter micron- scale particles and aggregates of nanoparticles present in the feed water which also resulted in the disinfection of 99% of viable bacteria (Escherichia Coli. By combining filtration, separation and disinfection with deionization, it is concluded that Shock Electro dialysis has the potential to demonstrate a highly compact and efficient water purification system [5].

However, it is seen that most of the applications are at the proof-of-concept stage and there has been a consistent effort to build prototypes for suitable commercial applications. Also, the quantum of reported literature on the works carried out is at bare minimum. This paper presents the design and analysis of the performance of a portable shock tube in treating saline water. The outcomes of this work will certainly form a basis for further analysis and enable fellow researchers to optimize the performance and utilize the shockwaves for the betterment of our mankind.

DESIGN -OF SHOCK TUBE

The main components of the shock tube are a driver section, a driven section and a diaphragm fixed between these sections by means of suitable flanges. The design of a shock tube is based on the initial assumption of the Mach number of the shock to be produced in the shock tube.

The speed of sound is estimated using the relation as below.

$$a = \sqrt{\gamma RT} \quad (1)$$

Velocity of the moving shock at the driven section is estimated as

$$V_s = M_s \times a \quad (2)$$

The pressure ratio and the temperature ratio of the driven and driver section is obtained using the relation as below.

$$V_s = a \times \sqrt{\left(\frac{\gamma+1}{2\times\gamma}\left(\frac{P2}{P1}-1\right)+1\right)} \quad (3)$$

and hence

$$\frac{T2}{T1} = \left(\frac{2+(\gamma-1)M^2}{(\gamma+1)M^2}\right) \times \left(1+\frac{2\times\gamma}{\gamma+1}(M^2-1)\right) \quad (4)$$

The diaphragm has to be designed to rupture at any P_4, which is estimated as below.

$$\frac{P4}{P1} = \left(\frac{\left(2\gamma M^2-(\gamma-1)\right)}{\gamma+1}\right) \times \left(1-\frac{\gamma-1}{\gamma+1}\times\frac{a}{a}\left(M-\left(\frac{1}{M}\right)\right)^{-\frac{2\gamma}{\gamma-1}}\right) \quad (5)$$

The pressure to be maintained in the driver section to obtain shocks of different Mach numbers and their corresponding velocity of the shock with respect to various Mach numbers is shown below in Fig 1.

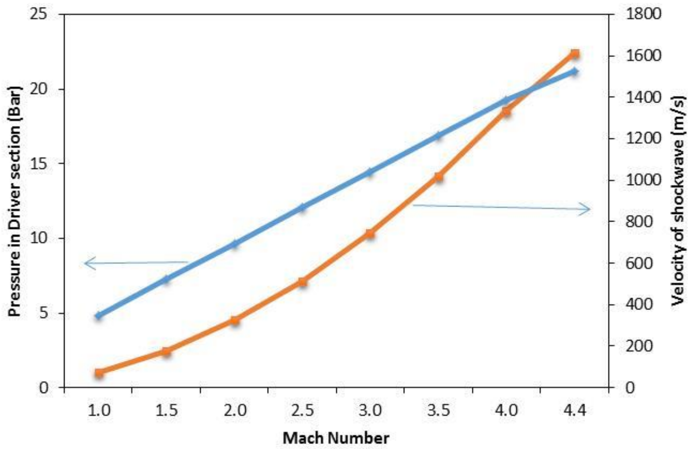

Fig 1. Variation of Pressure and velocity with Mach number

It is seen from Fig 1, that in order to generate a shock of higher Mach number, the pressure required in the driver section increases, while the velocity of the shock also increases linearly. Say for example, to produce a shock of 1.5 Mach, moving with a velocity of 520.9 m/s the pressure needed in the driven section is 2.46 bar. The maximum temperature expected in the driver section due to the maximum pressure in this section which the material should withstand is found from the Fig 2.

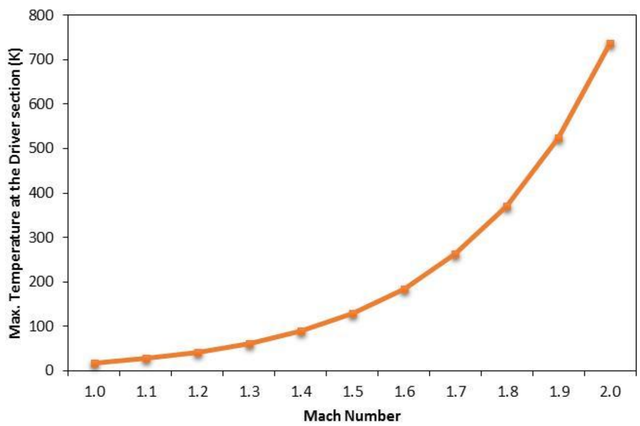

Fig 2. Variation of Pressure and velocity with Mach number

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Material Selection

Having known the pressure and temperature of operation of the shock tube, it is necessary to choose the right kind of material for its fabrication. The scope of excellent mechanical properties offered by various classifications and grades within the family of stainless steels make them versatile materials for these applications. Stainless Steel SS304 is chosen, as the properties of SS304 suits the requirement in addition to which it also possesses good corrosion resistance, oxidation resistance and it is also easy to form and weld.

The Hoop stress or circumferential stress in the tangential direction of the shock tube is estimated as

$$\sigma_\theta = \frac{Pd}{2t} \tag{6}$$

Based on the hoop stress estimation, the diameter and thickness of the pipe is chosen from the commercially available standard ones. The inner diameter, outer diameter and thickness of the standard pipe for schedule 40 are 20 mm, 26.67 mm and 3.335 mm respectively, which is estimated to withstand a pressure of 29.74 bar. The specifications of shock tube designed are obtained as below in Table 1.

Table 1. Specifications of the designed shocktube

Driver section Length	450 mm
Driven section Length	1500 mm
Inner Diameter	20 mm
Outer Diameter	26 27 mm
Material	SS304
Diaphragm	Standard A4 paper

EXPERIMENTAL ANALYSIS

The schematic representation of the shock tube facility developed for water treatment is shown in the figure 3.

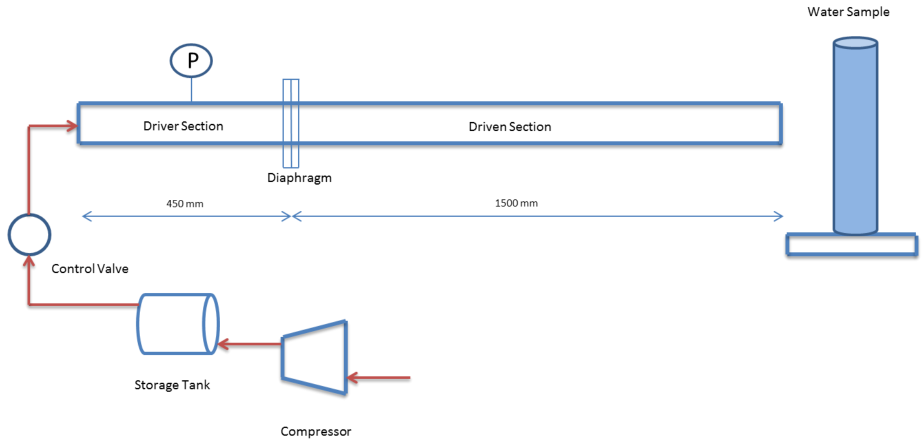

Fig.3 Schematic diagram of the portable shock tube based water treatment facility

The Shock tube receives compressed air from a storage tank where air is compressed and stored. The water samples to be tested are taken in plastic bottles. A control valve is used to adjust the flow of high pressure air flow to the shock tube. A Pneumatic valve is used to open and close the flange that holds the diaphragm. Preliminary investigations were conducted to estimate the bursting pressure of different diaphragms like A4 paper, heavy duty Aluminum foil and Aluminum sheets used for packing foods. The bursting pressures of different diaphragms are found to be as in Table 2.

Table 2. Estimated bursting pressure for various diaphragms

Sl. No.	Diaphragm Material	Thickness of Diaphragm (mm)	No. of diaphragms used	Total thickness of diaphragm (mm)	Bursting Pressure (bar)
1	Standard A4 paper	0.05	2	0.1	2.5
2	Aluminum Foil	0.016	10	0.16	3.8
3	Aluminum packing sheet (Food grade)	0.2	1	0.2	5.8

The velocity of the shock in the driven section is estimated by recording the peak pressures at two different points separated by a known distance on the driven section by microphones. The output of the microphones is recorded using Sound Forge 6.0 software. Three different water samples were chosen and subjected to shocks and the reduction in salinity is measured using a ppm meter. It is observed that the salt particle starts to deposit on the bottom of the bottle while the pure water starts to accumulate on the top. The outcomes of the preliminary experimental analysis are shown in Table 3.

Table 3. Reduction of salinity after shock treatment

Sample	**Type of water**	**No. of Shocks**	**TDS Measured Before Shocks (ppm)**	**TDS Measured after shocks (ppm)**	**% of TDS reduction**
A	Tap Water (Location 1)	250	582	553.2	4.9%
B	Brackish Water (From Borewell)	250	1908	1823	4.45%
C	Salt Water (20 g/ liter)	250	77300	75460	2.4%

CONCLUSION

A portable shock tube set-up for water treatment is designed and tested with three different types of water samples. It is found that the salinity reduction ranged from 2.4 % to 5% depending on the type of water sample. The salinity reduction in salt water to an extent of 2.4% is a positive indicator that this method can be used to desalinate water by increasing the number of shocks and also the burst pressure. Further investigations are needed to test the quality of water with different diaphragms and higher salinity water samples.

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