# Experimental Investigation of a Slug Motion in an Inclined Pipe System

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## Abstract

Liquid slugs trapped in a voided line may damage the pipe systems used in thermal power plants. Problems in those plants have been reported in the literature. In order to prevent the failures of the pipes, the impact pressures due to slugs should be predicted as accurately as possible. In the present study, slug motion is experimentally investigated. Experiments are conducted to measure impact force due to slug flow for a larger pipe diameter which represent the real piping systems better. An inclined pipe is used in the experiments, which is connected to a pressurized air tank and between them a ball valve is located. A slug mass or the initial slug length before each experiment can be set at the lower part of the pipe by using a water tank at the upstream. By opening the valve the liquid slug is accelerated due to the pressurized air at the tank and hits 90$^o$ degree elbow located at the downstream end of the pipe. After the elbow, the system is open to atmosphere with a short pipe segment. The pipe is rigidly attached to air tank and concrete floor. Due to extensive anchoring, the pipe can be assumed to be rigid and constrained from axial movement induced by the slug impact. To measure the pressure history, a pressure transducer is installed on the elbow.Peak pressures at the elbow are measured for different initial slug lengths. The experimental results obtained in this study can be used to validate different numerical approaches.

***Keywords:*** *waterhammer, transient flow, slug, power plant,*

## 1 Introduction

Isolated liquid slugs travelling in a voided line may potentially damage the pipe systems. These slugs accelerate and reach very high velocities and cause extensive damage on the pipe anchors or pipe elements when they hit the obstructions like valves, bends, etc. In order to prevent failure of the pipes and satisfy reliable operation, impact pressures due to slugs should be predicted as accurately as possible. Design engineers encounter this problem especially in the thermal power plants where steam turbines are used. Steam in the lower levels may form liquid slugs and these liquid slugs accelerate in the regions where pressure is high during the operation.

Researchers have studied impact peak pressures due to liquid slugs numerically and experimentally. The most important experimental studies have been conducted by Fenton and Griffith (1990), Bozkuş (1991), Owen and Hussein (1994) and Bozkuş et al. (2004). Numerical studies have been done by using these experimental works (Yang and Wiggert, 1998; Kayhan and Bozkuş, 2011; Hou et al., 2014; Tijsseling et al, 2016; Korzilius et al., 2017; Dinçer, 2017; Dinçer et al.,2018).

In the previous experimental studies of Bozkuş et al. (2004), the accelerated slug hits the elbow and leaves the pipe that is fully open to the atmosphere. The main novelty in the present study is that the pipe is partially open to atmosphere. Therefore, the change in impact pressure is investigated when air can leave the pipe only through a small orifice. In the next section, the experimental setup is explained in detail. Later, the results are presented and conclusions are drawn.

## 2 Experimental Setup

The experiments are conducted in the hydromechanics laboratory of Civil Engineering Department at the Middle East Technical University. The experimental setup and its sketch are shown respectively, in Figure 1 and Figure 2. The setup consists of a cylindrical air tank with a volume of 0.5 $m^3$ and located upstream, a 10 cm diameter ball valve, a vertical pipe with a length of 85 cm, 12 m long forward sloped steel pipe with a 10 cm inside diameter and an angle of $4.6^0$ with respect to a horizontal plane and a $90^0$ square elbow. After the elbow, the pipe is partially open to the atmosphere. The air tank is filled with pressurized air and the pipe segment just downstream of the valve is partially filled with water to form trapped liquid i.e. a slug of desired length. By opening the ball valve, the slug is accelerated and hits the elbow. A transducer is located at the elbow to measure time variation of the impact pressure. A computer equipped with a high speed A/D converter was employed to collect the data at the elbow.


**Figure 1.** Experimental setup

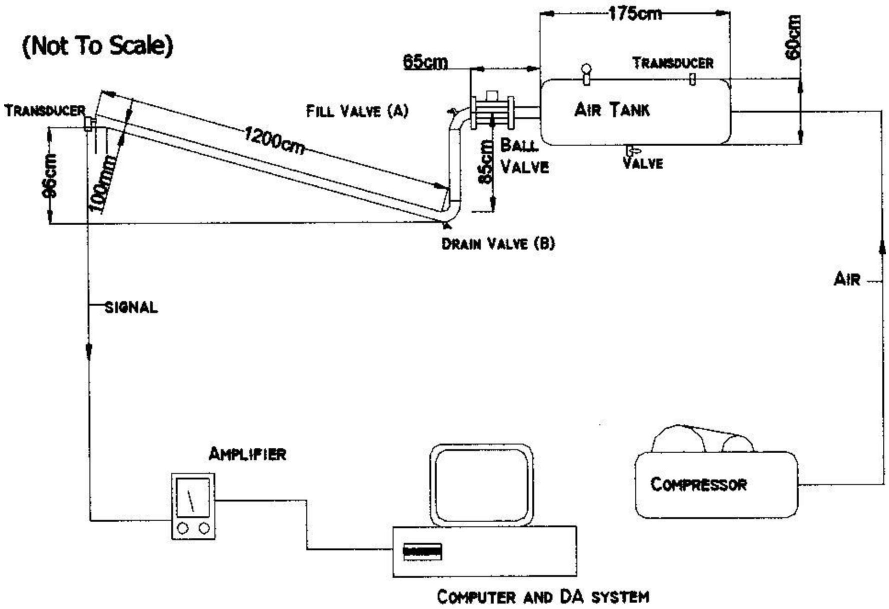


**Figure 2.** The illustration of experimental setup

Initial tank pressure, initial slug length, the distance travelled by the slug, the volume loss of the slug during the motion are the most important parameters effecting the impact pressure at the elbow. During the tests, the initial tank pressure and the initial slug length are controlled. In the tests, five different initial tank pressures, 2, 3, 4, 5 and 6 bars and various initial slug lengths are selected. In addition, the tests were repeated with different orifice openings. In the present study, the experimental results of slugs with an initial mass of 24 kg are presented. The initial tank pressures and orifice openings presented herein are 3 and 6 bars and 5 and 10 mm, respectively. The tests are repeated three times and repeatability is satisfied.

## 3 Experimental Findings

In Figure 3, pressure history at the elbow for a slug with an initial mass of 24 kg is shown. The initial tank pressure is 3 bar and the system is completely open to atmosphere. The peak pressure is approximately 13.3 bar.

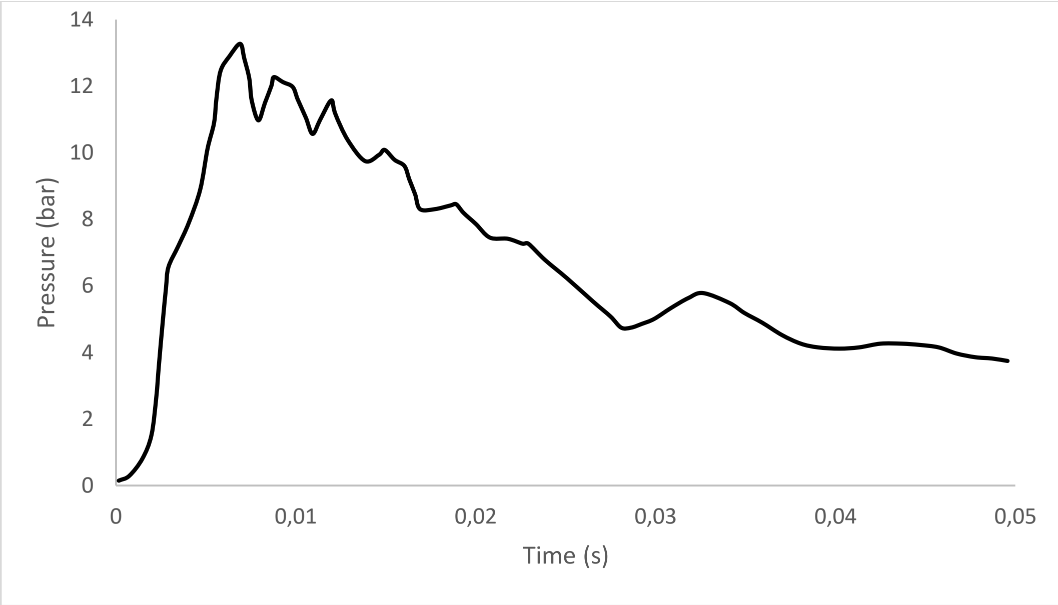


**Figure 3.** Pressure history at the elbow for 24 kg slug (tank pressure=3 bar, with completely open pipe)

**In**

Figure 4, pressure history at the elbow for 24 kg slug with an initial tank pressure of 3 bar and orifice opening of 10 mm is shown. Recorded impact peak pressure is approximately 4.5 bar which is nearly one third of the peak pressure when the system is completely open to the atmosphere.

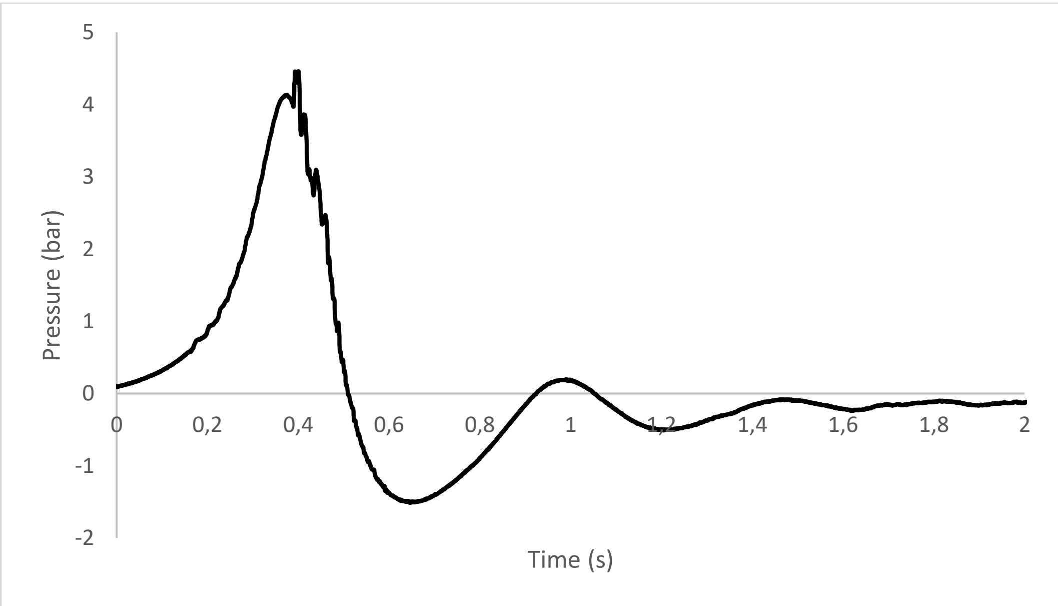

**Figure 4.** Pressure history at the elbow for 24 kg slug (tank pressure=3 bar, orifice opening= 10 mm)

**As the orifice opening is reduced to 5 mm, the respective pressure history is shown in**

Figure 5. The peak pressure is recorded as 2 bar which is half of the peak pressure when the orifice opening is 10 mm.

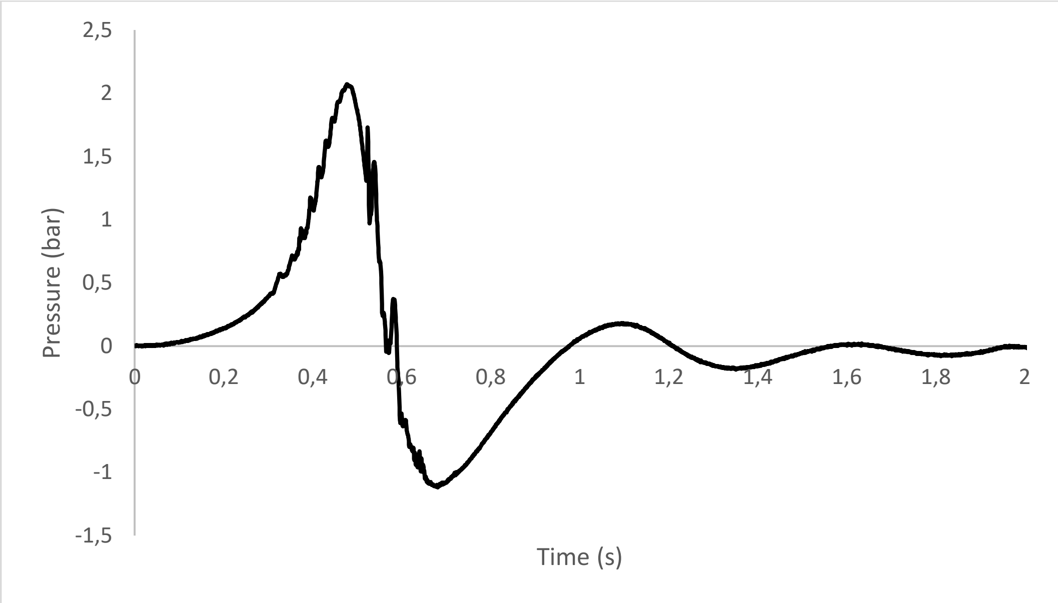


**Figure 5.** Pressure history at the elbow for 24 kg slug (tank pressure=3 bar, orifice opening= 5 mm)

In Figure 6 and 7, pressure histories at the elbow for 24 kg slug with an initial tank pressure of 6 bar and orifice openings of 10 mm and 5 mm are shown, respectively. Peak pressures are close to each other for both orifice openings.

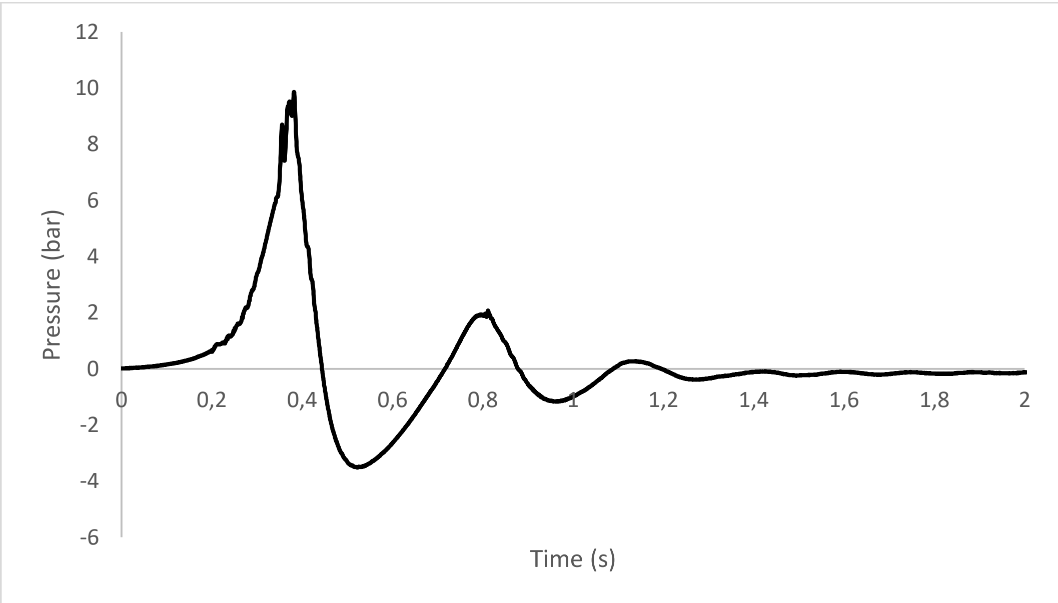


**Figure 6.** Pressure history at the elbow for 24 kg slug (tank pressure=6 bar, orifice opening= 10 mm)

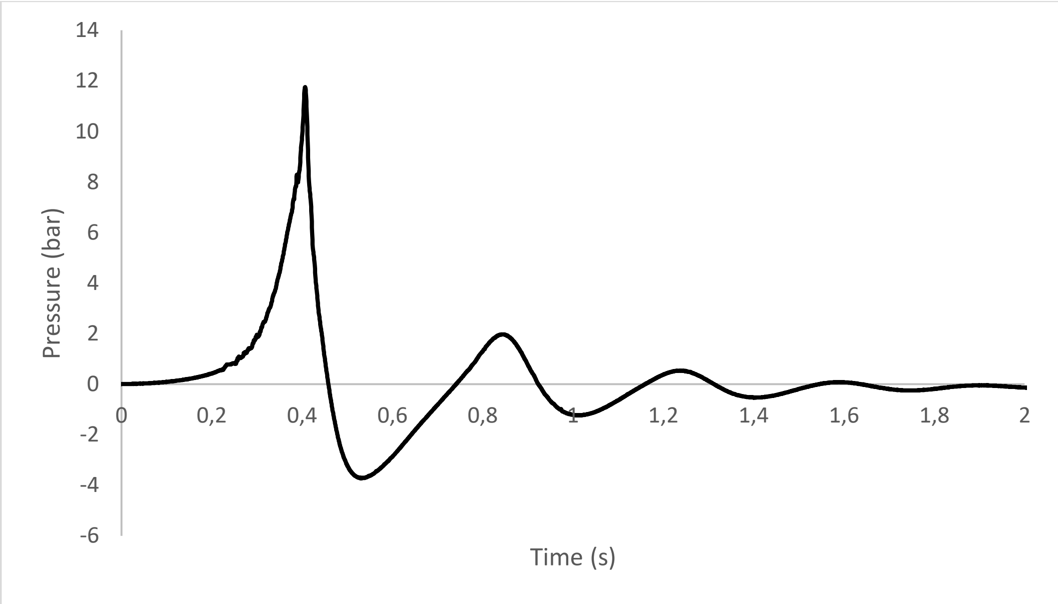


**Figure 7.** Pressure history at the elbow for 24 kg slug (tank pressure=6 bar, orifice opening= 5 mm)

## 4 Conclusions

In the present study, impact pressures due to accelerated slug hitting the elbow are investigated experimentally. In the experiments, the pipe is partially open to atmosphere and different orifice openings are selected. Experimental observations show that with the smaller orifice opening, lower impact peak pressures at the elbow are obtained. This is speculated that as the orifice opening gets smaller more air pocket is entrapped between the slug and the orifice, which acts like an air cushion. This, in turn, causes the peak pressure measured at the elbow to decrease. This is obvious for the experiments performed with the initial air tank pressure of 3 bars. However, interestingly it is not so in the experiments for higher initial tank pressures of 6 bars. These are just the preliminary results. Conclusive results will be available as more data measurements are investigated and analyzed in the near future.

## Acknowledgement

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