International Journal of Engineering, Mathematical and Physical Sciences
ISSN: 2517-9934
Vol:4, No:9, 2010

On the Characteristics of Liquid Explosive Dispersing Flow

Lei Li, Xiaobing Ren, Xiaoxia Lu, Xiaofang Yan

Abstract**—**In this paper, some experiments of liquid dispersion flow driven by explosion in vertical plane were carried out using a liquid explosive dispersion device with film cylindrical constraints. The separated time series describing the breakup shape and dispersion process of liquid were recorded with high speed CMOS camera. The experimental results were analyzed and some essential characteristics of liquid dispersing flow are presented.

Keywords**—**Explosive Disseminations; liquid dispersion Flow; Cavitations; Gasification.

I. INTRODUCTION

THE phenomena of liquid explosive dispersing have been studied for many years because of various applications in many industry areas and some ammunition domains (e.g. Fuel-Air Explosive weapon). The experimental device of liquid explosive dispersion consisted of a solid shell cylinder container filled with liquid and a burst tub (or initial explosive, detonating cord, detonator etc.) which is placed in the center of the container and vertical to the bottom confined plate, as shown in Figure 1.

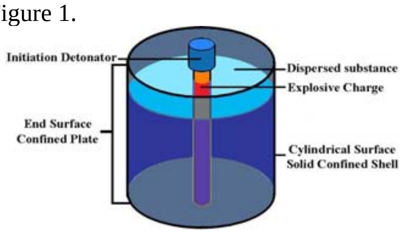

Fig. 1The model of liquid explosive

The process of liquid dispersion is driven by explosive shock effects. Before the solid shell's breakup the liquid in the container is impacted by explosive shock waves. After the solid shell's breakup, the liquid sprays outward from the splits of the solid shell and disperse to circumference. Because of the complicated mechanism of liquid break-up, disperse and mixing with explosive gas or ambient air, it counts particular investigations on liquid explosive dispersing flow.

Many researchers have made contributions including the numerical and experimental works to the problems.

Some scientists think that the liquid dispersing flow is a typical liquid-gas two phase flow of multi-scales in space and time. Therefore, based on the assumption that (a) the liquid is homogeneous after impact-action by shock waves, (b) the liquid flow is inviscid, incompressible, adiabatic and irrotational, (c) the liquid expands in radial direction and forms a continuous shell, Gardner[1] proposed a linear thin liquid shell instability model (see Figure 2). It was indicated that on the inner and outer interfaces of the liquid shell there are perturbations with smaller amplitude than the thickness of the liquid shell at the initial state. As the amplitude of perturbation on interfaces is larger than the thickness of shell, the liquid shell may breakup. The photos from Samirant's experimental works about the liquid shell obtained by flashing X-ray photographical technology[2] might support the model of Gardner (see Figure 3).

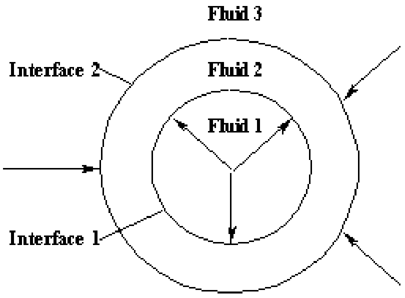

Fig..2 Gardner proposed model - a linear thin liquid shell instability model

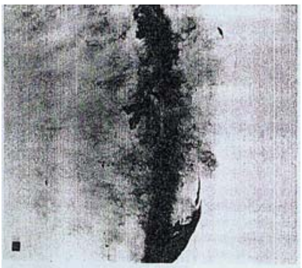

Fig..3.Liquid shell in expansion from Samirant by Flsah X-Ray photograph

However, on the photos provided by Samirant the shape of interface or liquid shell is irregular and in disorder, and it is difficult to confirm whether they are homogeneous fluid

---

L. Li is with the School of Aerospace, Tsinghua University 100084, P.R.China (corresponding author to provide phone: 86-010-52563861; fax: 86-010-62795211; e-mail: rockysys07@bbn.cn)

X.B. Ren is with the School of Aerospace, Tsinghua University 100084, P.R.China (e-mail: renbing202@sohu.com)

X.X. Lu is with the School of Aerospace, Tsinghua University 100084, P.R.China (e-mail: xiaoxia@ustc.edu)

X.F. Yan is with the School of Aerospace, Tsinghua University 100084, P.R.China (e-mail: fecho2001@163.com)

volumes. In addition, Gardner didn’t explain why the liquid will expand as a continuous shell after the explosive action. And before the solid shell’s break-off, with impetuous action of explosion and the penetration of shock waves the liquid can be compressed or stretched. Which effect is more important? Do the homogeneous or continuous liquid shells exist? There were no answers reported by Gardner and Samirant for these basic problems. Based on the assumption of existence of a homogeneous liquid shell, some people applied the mechanism of Rayleigh-Taylor instability (RTI) or Richtmyer-Meshkov instability (RMI) on the process of liquid shell expanding and gave some explanations to the dissemination process[3]. But because the main actions are the acceleration of interfaces between heavy and light homogeneous fluid and the pulse passing interfaces of gas by shock wave in RTI and RMI, it is difficult to judge whether they can represent the complicated processes of liquid breakup and disperse after the shell broken.

In this paper, some experiments of liquid dispersion flow driven by explosion in vertical plane were carried out using a liquid explosive dispersion device with film cylindrical constraints. The separated time series describing the breakup shape and dispersion process of liquid were recorded with high speed CMOS camera. The experimental results were analyzed and some essential characteristics of liquid dispersing flow are presented.

II. EXPERIMENTS OF LIQUID DISPERSION FLOW IN VERTICAL DIRECTION

The experiments to liquid dispersion process were performed under the conditions of linear type initial explosion by a detonation cord and recorded from an observing window. The global sketch of experimental set-up and disposal of measure devices is shown in Figure 4. The liquid dispersion device is consisted of two end aluminum confined round disks and colloidal confined cylindrical shell, in which liquid is filled with no gas bubble (see Figure 5). The liquid dispersion flows after explosion was recorded by high speed CMOS camera named Redlake MotionXtra HG-100K.

The experiments are carried out under different conditions, in which the primary adjustable parameters are explosive density of the detonation cord or the explosive charge, diameter of the cylindrical film, and viscosity of the liquid. Experimental observations and main results are presented here.

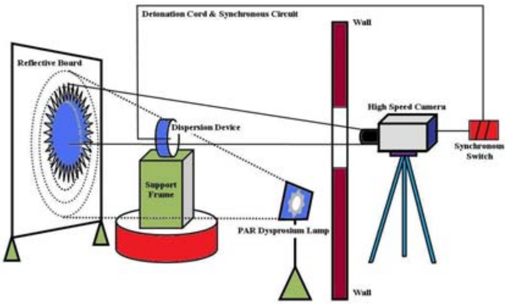

Fig. 4 The sketch of experimental site and measure devices

(1) The explosive density of detonation cord is 3g· m^{-1}, the diameter of cylindrical film is 150mm. The liquid is water. Four recorded photos are shown in Figure 5.

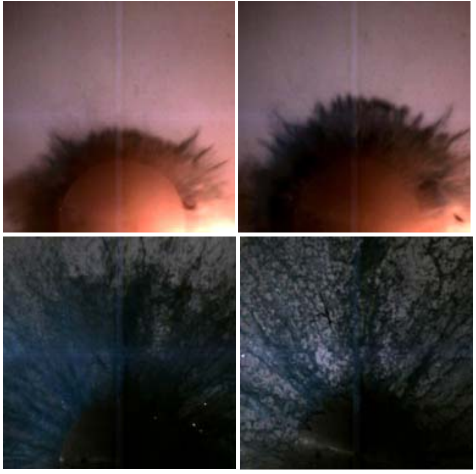

Fig. 5The shape of water dispersion flow, detonation cord is 3g· m^{-1}, the diameter of cylindrical film is 150mm

In Figure 5, the anterior two pictures are seventh (2.33ms) and twelfth (4.0ms) pictures after initiation and it’s flashing picture. In the two pictures, the early shape of liquid rushing out after film broken is recorded. It is shown that the shape of liquid dispersion flow ejecting from orifice of the broken film is similar to pin-like spike with homogeneous distribution around circumference.

The latter two pictures in Figure 5 are forty-eighth (16.0ms) and ninetieth (30.0ms) pictures after initiation and its flashing picture. In the pictures, the developing shape of liquid spraying out after film broken is recorded. It is shown that as the liquid dispersion flow developing, the pin-like jet flows disperse to circumference, intersect in radial direction, and intercross in tangent direction of circumference, and form tree-like shape with homogeneous distribution in wholly dispersion field. In gradually, the tree-like liquid flow becomes to rarefaction ligament flow which will break into drops by the action of liquid surface tensions or stretched to fine silk flow.

(2) The explosive density of detonation cord is 5 g· m^{-1}, the diameter of cylindrical film is 150mm. The liquid is water. Four recorded photos are seen in Figure 6.

In Figure 6, the anterior two pictures are twelfth (2.4ms) and twentieth (4.0ms) pictures after initiation and it’s flashing picture. In the pictures, it is shown that the early shape of liquid dispersion flow ejecting from orifice of broken film is also similar to pin-like spike. Because of the explosive charge increasing, the action by explosion is strengthened, so that the number of pin-like jet flow is greater, the distribution is more homogeneous and the shape is more pointed and longer. And by the force of explosive product gas, the central liquid dispersion annular range is formed. By the brighter part in the pictures, it is indicated that the annular range is considered as a group of discontinuous liquid jet, or ligament.

The latter two pictures in Figure 6 are twenty-fifth (5.0ms) and thirtieth (6.0ms) pictures. In the pictures, the developing shape of liquid dispersion flow in circumference forced by explosive gas is recorded. Due to the forcing action of explosive gas, the annular range of liquid jet flow becomes to rarefaction gradually, and in the last, the liquid jet breaks up to drops.

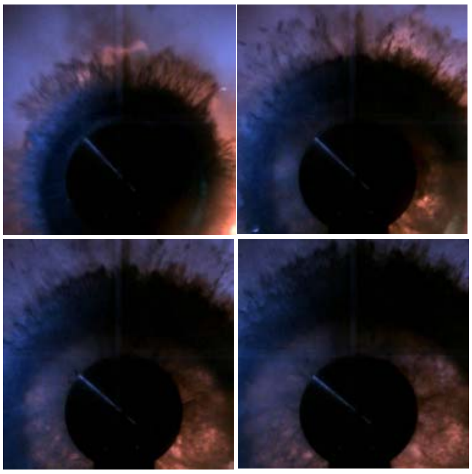

Fig. 6The shape of water dispersion flow, detonation cord is 5g · m^{-1}, the diameter of cylindrical film is 150mm

(3) The explosive density of detonation cord is 11 g · m^{-1}, the diameter of cylindrical film is 145mm. The liquid is water. Four recorded photos are seen in Fig. 7.

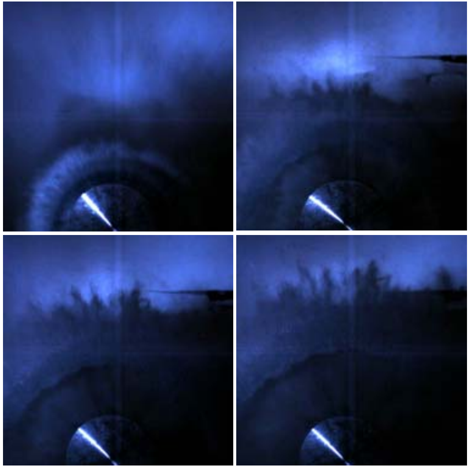

Fig. 7 The shape of water dispersion flow, detonation cord is 11g · m^{-1}, the diameter of cylindrical film is 150mm

In Fig.7, the anterior two pictures are eighth (1.6ms) and twentieth (4.0ms) pictures after initiation and it's flashing picture. The early shape of liquid dispersion flow ejecting from orifice of broken film similar to pin-like jet is shown in the pictures. Because of the explosive charge increasing greater, the action by explosion is more strengthen, so that the distribution of pin-like jet flow is more homogeneous and much fine. And by the force of explosive product gas, the central liquid dispersion annular range is also formed. In the pictures, it is indicated that the annular range is considered as a group of discontinuous liquid jet. Further, by the white color of the annular range, it is considered that the liquid annular range is consisted of breaking drops, cavitations bubbles or evaporating liquid gas.

The latter two pictures in Figure 7 are twenty-fifth (5.0ms) and thirtieth (6.0ms) pictures. In the pictures, due to the forcing action of explosive gas, the liquid dispersion flow is developed and the radium of annular range is increased. And in the last, with the liquid annular range becoming to rarefaction gradually, the liquid breaks up to mini drops directly.

Figure 8 is the recording picture about the developed annular shape of liquid dispersion flow from other two experiments. Here, it is a situation in which the explosive density of detonation cord is 5 g · m^{-1}, the diameter of cylindrical film is 115mm, and the liquid is mixture of water and glycerin with capacity ratio of 5:5. Further, they indicate that due to the forcing action of explosive gas, the liquid dispersion flow is developed to the annular range becoming to rarefaction gradually and breaking up to mini drops directly.

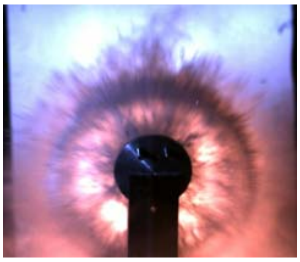

Fig. 8 The shape of liquid dispersion flow, when the detonation cord is 5 g · m^{-1}, the diameter of cylindrical film is 150mm. The liquid is the mixture of water and glycerin with capacity ratio of 5:5

(4) The density of explosive charge is 54.55 g · m^{-1}, the diameter of cylindrical film is 135mm, and the liquid is water. Two recorded photos are seen in Figure 9.

In Figure 9, two pictures are the recording picture about the developed shape of liquid dispersion flow, where the characters of gas and spray state are more obvious in the annular range, as like gasified liquid disperse rushing outward from cylinder.

In other experiment, the explosive charge is 29.3g, the diameter of cylindrical film is 135mm, and the liquid is water. Two recorded photos are seen in Figure 10. Here, the character that liquid is gasified becomes obviously more and more.

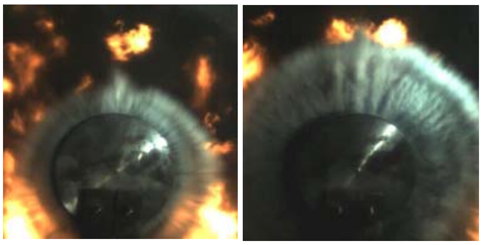

Fig. 9 The shape of water dispersion flow, when the density of explosive charge is 54.55 g · m^{-1}, the diameter of cylindrical film is 135mm

Fig. 10 The shape of water dispersion flow, the explosive charge is 29.3g, the diameter of cylindrical film is 145mm

(5) The density of explosive charge is 5 g · m^{-1}, the diameter of cylindrical film is 145mm, and the liquid is glycerin. The recorded picture shows the liquid dispersing flow composed of larger drops, sheets and ligaments (See Figure 11a).

But when the density of explosive charge is increasing to 54.55 g · m^{-1}, the recorded picture also shows the liquid glycerin dispersing flow showing spray and pin-like jet shape (See Figure 11b). When the viscosity of liquid is about 1000 greater than glycerin (may be a kind of non-Newtonian fluid), the liquid dispersing flow is composed of larger drops, ligaments (See Figure 11c), and no gasification behavior.

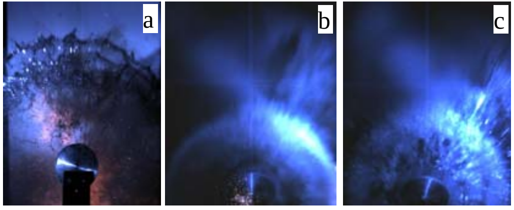

Fig. 11 The shape of liquid dispersion flow
a: the liquid is glycerin and the detonation cord is 5 g · m^{-1}. b: the liquid is glycerin and the density of explosive charge is 54.55 g · m–1. c: the liquid is a kind of non-Newtonian fluid which viscosity is about 1000 great than glycerin and the density of explosive charge is 54.55 g · m–1.

Above recorded pictures (Figure 5, 6, 7) may be published in other papers, such as [4], [5], [6], the reader can be refer to them.

III. ANALYSES TO THE EXPERIMENTS

From the above experimental results, there are some conclusions as following.

(1) Liquid dispersion flow is an unsteady flow with a group of pin-like jet, rushing out, expanding by blast force and distributing in circumference homogeneously.

(2) In early stage, the front of liquid dispersion flow is like to jet flow with rarefaction distribution (the number of jet may depends on the crack width of outer film), following the central dispersion flows are pin-like jet flow with dense distribution.

(3) If the driven explosive charge is small, the pin-like jet flows intersect or intercross gradually and become a group of ligament with tree-like shape in wholly dispersion field. If the driven charge is increased, the force of explosive gas becomes greater, so that an annular central liquid dispersion flow range is formed.

(4)The front of liquid annular range has also shape of pin-like jet, the width of liquid annular in radial direction is increase, and as long as the driven charge being greater, the pin-like structure becomes fine, the annular central range with white color is consisted of breaking drops, cavitations bubbles and evaporating liquid gas.

(5) With the forcing action of explosive gas, the annular central liquid dispersion flow range becomes rarefaction gradually, and in lastly liquid jet or ligament break up to drops.

(6) If the driven explosive charge is much greater, the characters of gas and spray state are more and more obvious in the annular central range, as like gasified liquid disperse rushing outward from cylinder.

(7) If the viscosity of liquid is greater, such as glycerin, when density of explosive charge is small, the liquid dispersing flow is composed of larger drops, sheets and ligaments. When the density of explosive charge is greater, the liquid dispersing flow shows spray and pin-like jet shape. When the viscosity of liquid is much greater, some properties of non-Newtonian fluid will play a role in the liquid dispersing flow which is composed of larger drops, ligaments and volumes, and no gasification behavior.

Why the liquid dispersing flow will present above characteristics? By all appearances, the assumption “(a) the liquid is homogeneous after impact-action by shock waves” and “(c) the liquid is expanding in radial direction and form a continuous shell” are not correct, they neglect the impetuous action of explosion and the penetration of shock waves the liquid.

In fact, when the explosive detonates, there is an impetuous action of explosion to the nearby liquid, and a density rising range will become and increase gradually. The density rising range is the compression range of liquid. When the detonation product gas expand to double diameter of explosive charge, the speed of expansion outward will decrease to the sound speed of liquid, and liquid is not be compressed further and moving forth. Then the impetuous action stop and the blast action begin. Meanwhile, as the reflecting shock wave move back to the center of explosion, the shell begins to expand. Later, as the pressure near the cylindrical confined shell will decrease, the compression range reduces, non-compression range increases, and the process can continue up to an equilibrium state.

Obviously, before the cylindrical shell break-up, liquid have been two states that the outer liquid near cylindrical shell is in non-compression, but the inner liquid is in compression. There is different dispersing process respectively between the inner liquid and outer liquid. Because of the compressive potential energy accumulated within the density rising period, the inner liquid will expand instantaneously around circumference, and break-up to drop in every place of the inner region. Due to the kinetic energy transferred from detonation product gas, the outer liquid is thrown to ambient space and is impacted by air drag force, and is broken-up to drop in the last by many breakup processes. The former can be called inertial dispersion and the latter can be called turbulent dispersion.

Therefore, the dispersion flows in recorded pictures in

Figure 9 and Figure 10 are inertial dispersion, those in Figure 6 are typical turbulent dispersion, and those in Figure 8 are the mixture of inertial and turbulent dispersion. They can be shown in the following picture (Fig.12).

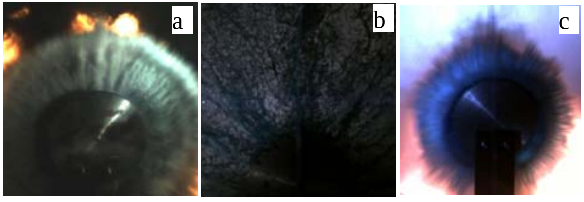

Fig. 12 Several patterns of liquid explosive dispersing flow. a: Inertial dispersion; b: Turbulent dispersion; c: Mixture of inertial and turbulent dispersion

IV. CONCLUSIONS

In this study, the authors carried out a series of experiments to reveal some distinct characteristics of liquid explosive dispersing flow. Based on the above experimental results and analyses, some deductions can be summarized as follows.

(1) The reasonable partition of liquid explosive dispersion process should be two stages, the first is before and the second is after the container's broken.

(2) In the first stage, after explosive detonation and shock wave reaches the container's shell, liquid can be divided to two parts of different states. The liquid close to the explosive charge is greatly compressed during the impetuous explosion while the liquid close to the container's shell is in non-compression after the penetration of shock waves. In the former region, the accumulating the potential energy in the density rising range may lead to gasification and decomposition of liquid. It is shown that thermodynamic transition and chemical reaction of liquid may appear during the explosion instant. In the latter region, the kinetic energy transferred from the blast waves may lead to the cavitations of liquid. It is shown that the cavitations of liquid may occur during the process of reflecting rarefaction.

(3) The different states of liquid result in different dispersion patterns. The intense compression of the liquid of inner region may lead to inertial dispersion and the turbulent dispersion may occur in the outer region where the liquid is in non-compression. During the decompression process, gasification and decomposition of liquid may occur with large potential energy, while cavitations of liquid may occur with large kinetic energy.

(4) In the second stage, the spraying out liquid dispersion flow is formed as inhomogeneous blocks, ligaments, drops or fragments, and it is a kind of gas-liquid multiphase or multi-component flow. Furthermore, due to the flow front shape of pin-like jet is related to the crack width of confined filmy crust, the liquid dispersion flow is depending on the breaking characters of container's crust.

A perfect mathematical model of liquid explosive dispersion process has not yet been developed. The main difficulties focus on the equations of state of liquid under the impetuous explosion and blast wave action of explosion, and the conditions of cavitations production. Further experimental studies may be focused on when, where and what degree the cavitations will occur and the temperature and pressure measuring of the liquid before the container's broken. And based on the quantitative results, a more accurate model to describe the characteristics of liquid explosive dispersion process may be developed.

REFERENCES

[1] D R Gardner."Near-field Dispersal Modeling for Liquid Fuel-air-explosive". DE91000079 (SAND-90-0686),1990.

[2] M.Samirant, G.Smeets, Ch.Baras, H.Royer,and L.R.Oudin, "Dynamic Measurements in Combustible and Detonable Aerosols", *Propellants, Explosive & Pyrotechnics*,vol.14,pp.47-56,1989

[3] J.H.Wang, *Unsteady Flow and Shock Wave in Two Dimensions (in Chinese)*. Beijing: Science Press, 1994, ch5.

[4] L.Li, J.Cui, Y.C.Dong, "Experimental investigations to the interfaces breakup during liquid explosive disseminations process",*Chinese Science Bulletin*, vol.54, no.12, pp. 1693-1700, 2009.

[5] X.X.Lu, L.Li, X.B.Ren , X.F.Yan, Y.C.Dong. Numerical simulations of interactions between shock wave and gas-liquid-air interfaces. *Journal of Physics: Conference Series* vol.216, 2010.

[6] X.B.Ren, X.X.Lu, L.Lei, X.F.Yan, Y.J.Ren, "Experimental Research and Numerical Simulation of Liquid Explosion Dispersion", *Acta ArmamentarII*, vol.31, suppl.1, pp.93-97.