Vinogradov S.A.

The usage of high speed impulse liquid jets for putting out of gas blowout

Vinogradov Stanislav Andreevich, philosophy doctor, senior lecturer,
National University of Civil Defense of Ukraine, Kharkiv, Ukraine

Abstract. The experimental researches of gas flame suppression by means of high speed impulse liquid jet generated by powder impulse hydro-cannon have been carried out. The speed of the impulse jet depending on a charge energy ranged in the experiment from 300 to 600 m/s. By means of the laser non-contact measuring device the speed of the head jet right near the gas flame has been measured, the flow has been photographed. It has been shown that round the high speed impulse liquid jet in the air the high-speed cloud of splashes with the big cross-section is being formed which effectively forces down a flame of the gas flame on distances 10 - 20 m from installation.

Keywords: *impulse liquid jet, powder impulse hydro-cannon, gas blowout.*

Introduction. Fire extinguishing represent a complicated man-caused emergency. Response actions to such an emergency require substantial financial expenditure and involvement of a great number of firefighting equipment units and manpower. Open blowouts as for their power level are divided into [1]:

- small-scale with gas output less than 0,5 mln m^3 per day and oil output less than 100 t per day;
- medium-scale with gas output (0,5÷1,0) mln m^3 per day and oil output (100÷300) t per day;
- powerful with gas output (1,0÷10,0) mln m^3 per day and oil output (300÷1000) t per day;
- high-power with gas output more than 10 mln m^3 per day and oil output more than 1000 t per day.

Practice shows that fire and accident occurrence in oil and gas wells amounts on average to 0,12 cases in 100 wells [2]. For instance, in the fields based in Texas number of blowouts during prospecting drilling amounts to approximately 244, during development drilling on a well it makes up 180, during well completion − 64, during well work over (also called reworking) − 197, during well operation − 85. In the fields located on American continental shelf, number of blowouts is lower and makes up respectively 45, 49, 25, 23 and 12. It is due to a smaller quantity of wells and to the usage of more reliable well casing design and down hole and wellhead equipment.

1. Modern methods of putting out of gas blowout. At least ten different methods of fire extinguishing of oil and gas blowouts have been developed because of an outstanding complexity of the technical problem on one hand, and of limited efficiency of each method on the other hand [3]. In the paper [4] are provided main methods of putting out of gas flame fires according to their type.

The carriage barrels (hydraulic monitors), gas-water firefighting cars (AGVT-100 and AGVT -150) and pressure-operated powder flame-arresters (PPP-200) are widely used in Ukraine and in other CIS countries for the purpose of fire extinguishing in open blowouts [3].

The hydraulic monitors are used for putting out of gas, gas-condensate and oil open blow-out of small power, because their barrel should be installed at a 15 m distance, which is not allowable for the putting out of blow-outs with bigger output [5]. Several hydraulic monitors are used for putting out of the open blow-outs of medium-sized power and water delivery is implemented at two levels. For a long time this method of putting out the gas blow-outs has been the leading one. It consists in the following: water jets supplied from hydraulic monitors are directed on the well mouth at blow-out base. Afterwards the water jets are raised up synchronously until complete flame lift-off from the well.

The gas-water firefighting cars (AGVT-100 and AGVT -150) are used for putting-out of all kind of the blow-outs, but more often for powerful blow-outs. The gas-water jets produced by these plants represent an inert mixture of exhaust gas of a turbojet engine and water spray. The gas-water jets are made up of 60% of water and 40% of gas. The oxygen concentration is not more than 14% at barrel outlet. More far from the nozzle the higher is the oxygen concentration and at a working distance of 12-15 m it makes up 17-18%. The water evaporates partially at gas burning hot jets, water at sprayed state arrives to burning zone [3].

The pressure-operated powder flame-arresters PPP-200 are used for putting out of high-power blow-outs [3]. The putting-out is done due to powder influence on the burning torch. The powder discharge is carried out at the expense of compressed air energy. The fire extinguishing powder concentration is created during a short period (1-2 s) by directed volley discharge.

The similar principle is implemented in devices based on tank chassis T-62 (Impulse–1, Impulse–2, Impulse–3 as well as Impulse–Storm). The device has 50 barrels (Impulse-1 has 40 barrels), each of them has 30 kg of powder. The Impulse–Storm device can deliver 1,5 tons of extinguishing powder in 4 seconds. This permits to create a powerful fire extinguishing impact at once and simultaneously through the whole area and volume. The main feature of this device is its powerful impact action on the fire seat together with its fire extinguishing effects produced by special powder mix.

The method of high explosive detonation is often used. The impact wave of high speed is generated (up to 1000 m/s) [2-5]. High explosive charge is delivered to the mouth of the well through wire rope or by a rail track car. The main weak points of this method are high danger, big and complicated preparation work and big quantity of high explosive necessary (100 – 1000 kg).

Methods of open gas and oil blowouts killing with prior flame extinguishing and subsequent elimination of flowing well as an exploration site have become widely spread in the world practice [2, 6].

It is worth pointing out that along with advantages of above listed methods all of them are characterized by a common disadvantage. This drawback consists in short delivery distance of fire extinguishing agent and that is inadmissible in the presence of high heat radiation of gas flame. Thus, while extinguishing method by means of carriage barrels and gas-water extinguishing cars the optimal delivery distance is 15 m [3, 4, 5], and safety distance L_{safety} for manpower from flame with the output V =0,5 mln. m^3/day is equal approximately to 50 m (fig. 1).

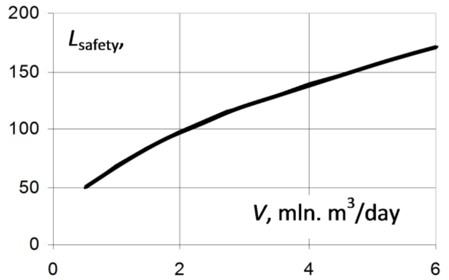

Fig. 1. Safety distance from burning gas flame

Thus, for fire-fighting and putting-out of gas blowouts the most promising of technologies is to develop devices that can guarantee the discharge of fire-extinguishing mixtures from distances which are safe for personnel considering heat emission.

2. Promising areas of development of gas blowout extinguishing devices. In all times the most available and simple fire-fighting resource has been water. Water is widely used in firefighting practice. It is evident that among gas blowout extinguishing mediums water is the most used agent compared to other extinguishing means due its availability, cheapness, simple delivery and use, as well as its high fire extinguishing properties.

For the time being the most promising fire-fighting method is the use of fine-water mist. The main mechanism of putting out the fire by fine-water mist is cooling of burning material and formation of a steam cloud, which localizes the burning center. If the drops do not have enough kinetic energy, they will not be able to overcome the barrier of convective stream of hot gas, which is generated by flame, and as the result will not be able to reach the flame surface and neutralize this process. In this case fine-water mist could only be used as an auxiliary mean and not the main fire-fighting method.

The drop diameter influences mainly the effectiveness of putting out procedure. Decreasing of drop diameters in fine-water mist can considerably decrease water rate necessary for putting out of the flame. At the same time decreasing of particle size obstructs maintenance of drop high speed and promotes faster drop evaporation in zone, which is previous to flame. This factors decrease the effectiveness of fine-water mist putting out. The analysis of different authors prove that optimal drop diameter is equal to $d_{drop} \in (100 \div 150)$ mkm [7].

For water delivery from safety distance to the burning flame it is necessary to support the high speed at fire-fighting device output. Calculated value of this speed should take into account losses during the jet flight and provide required speed directly before blow out for overcoming of convective stream as well as "separated" impact on blow out. The equilibrium position of blow-out flame drifts with flow with increasing of the flow speed. This is the substance of "separated" impact. The recent aero-steam ignitable mixture becomes more and more diluted with moving away due to reciprocal diffusion with steam. This mixture speed decreases proportionally to the dilution degree and exceeds the burning speed at some critical steam value; the jet is broken for a moment, and the flame is driven upward and separated from it.

The speed of flame separation can be calculated on the basis of the following empirical formula [8]

$$V_{separation} = 100\sqrt[3]{d}, \qquad (1)$$

where d – initial diameter of flame blow-out in meters.

The analysis of specific data concerning flame character changes with increasing of the speed of burning jet shows that separation of diffusion flame is going on at 80 – 100 m/s. It is evident that mentioned values of speed from safety distance (110 – 130 m) could be guaranteed with high speed liquid jets. These jets are generated by devices which are similar to impulse hydro cannons.

3. Schemes of the performance of the experiment. In order to prove the possibility of putting out of gas flames by high speed impulse liquid jets and to define necessary extinguishing parameters experimental studies have been carried out. The purpose of these experiments were to determine whether it is possible to put out gas blow-outs by impulse hydro cannon, to determine the running speed of cross flow of liquid in which the flame is extinguished, and to define the zone to which the jet should be aimed in order to guarantee flame extinguishing process.

Gas blowout model has been calculated on the basis of aerodynamical similarity factor, which characterizes the processes of gas mixing with surrounding atmosphere. It depends on pressure and gas jet thickness.

$$K_{an} = \frac{w_0^2}{2gd_0}, \qquad (2)$$

where w_0 – gas outflow velocity, m/s, g – speed-up of free fall, d_0 – well diameter, m.

Gas blowout modeling for blow-out burning with output $(1 \div 3) \cdot 10^6$ m^3/day has been carried out. Mas tree wells diameters (0,065÷0,3) m. In the experiments the simulative fire seat of gas blow-out corresponding to average parameters has been used.

In fig. 2 the scheme of performance of the experiment aimed at speed definition of the cross flow of the liquid enough to put out the gas flame.

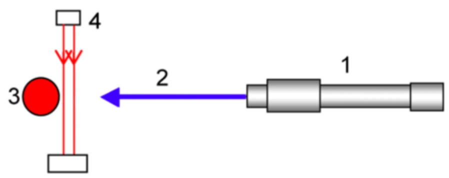

Fig.2. Scheme of experiment performance that is aimed at speed definition of the cross flow of the liquid when the gas flame is extinguished: 1 – powder impulse hydro-cannon, 2 impulse jet, 3 – simulative gas blow-out fire seat, 4 – speed measuring device.

From the impulse-type hydro-cannon 1 a series of shots with high-speed impulse jet 2 have been made onto the simulative gas blow-out fire seat 3. Qualitatively the burn termination has been registered and the high-speed jet speed at the torch has been measured with the help of speed measuring device 4 at different distances from the impulse water-gun to the torch. The distance from the plant to the torch has been measured by measuring tape.

Layout of the powder impulse hydro-cannon by means of which was carried out the experimental research is described in the fig. 3 [9].

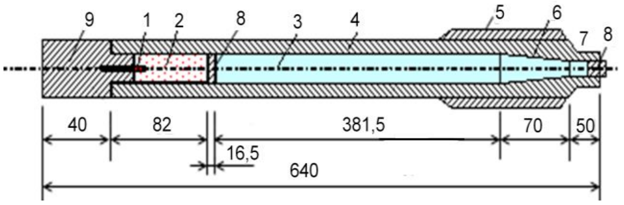

Fig. 3. Powder impulse water-gun: 1 – igniter, 2 – combustion chamber, 3 – water, 4 – barrel, 5 – binding belt, 6 –nozzle, 7 – collimator, 8 – wad, 9 – gate.

The barrel 4 of powder water-cannon, that at the end has a conical nozzle 6 with a collimator 7 is filled up with water 3. Charge of gun-powder 2 is separated from water charge 3 by means of a wad 8. For reinforcement the most stressed section of the barrel is strengthened by a binding belt 5, fixed on the barrel with backward tension. Gun-powder charge 2 in the casing of water-gun is fixed by a gate 9, inside which there is an igniter 1. At the start time the igniter 1 is actuated and fires the gun-powder charge 2. Powder gases that are generated during powder burning start expulsing and ejecting water charge 3 through the conical nozzle 6 in the form of impulse liquid jet. The outflow of liquid jet starts with a relatively small velocity that increases with increasing the pressure of powder gases. Detailed description of the powder impulse water-gun and theoretical calculations of its main parameters are presented in the work [10].

4. Experiments of putting out the simulative/model gas blow-out by means of a hydro-cannon. In the first stage of experimental research the motion speed of cross flow of the dropping liquid, at which the simulative gas blow-out fire seat is extinguished has been defined. A series of fire shots have been made from distances of 5, 10, 12 and 15 meters for powder charges of 5, 10 and 15 g. In the experiments the speed of impulse jet head section before the torch has been measured, the jet has been photographed and video filmed at its different diffusion stages. The speed of the head section of the jet was measured by means of non-contact laser speed measuring device that allows to record the speed in the range from 50 to 3000 m/sec. The results of such experiments are shown in the table 1.

The analysis of the videogram in the fig. 6 has shown that the jet approaches the gas torch (b) and isolates the burning zone from arrival of fresh gas and air mix (c, d). Further (e, f) the jet impact zone increases, between the burner and the flame is generated a rupture out of gas, water and liquid drops mix. The gas concentration in the rapture zone is lower than the concentration limit of flame diffusion, that prevents from burning renewal. The restarting of burning is prevented as well by the fact that the speed of after-burning of combustible gas is higher than the speed of arrival of new combustion products.

The carried out experiment have shown that impulse liquid jet of powder hydro-cannon can extinguish a simulative gas blow-out fire seat at a distance of 10 meters and more. Further research of gas torch extinguishing by high-speed impulse liquid jets must be aimed at studying how to optimize the parameters of powder hydro-cannon, at studying of the choice of efficient layout of impulse hydro-cannon and at analyzing of diffusion dynamics of impulse liquid jet in the air.

Table 1.

Results of experimental research

№	Powder mass, g	Distance from hydro-cannon to the torch, m	Speed at the torch, m/sec	Result of putting out the torch: + - extinguished – - not extinguished
1	5	5	227	+
2		10	87	+
3		15	63	-
4		12	71	-
5	10	5	338	+
6		10	105	+
7		15	69	-
8		12	82	+
9	15	5	428	+
10		10	125	+
11		15	78	-
12		12	108	+

Thus it has been stated that the motion speed of the cross flow of dropping liquid at which the extinguishing of simulative gas blow-out fire seat occurs is in the range (80÷90) m/sec that confirms our theoretical assumptions.

The torch extinguishing process by means of high-speed jet has been studied through video filming. In the fig. 6 the videogram of this process is provided.

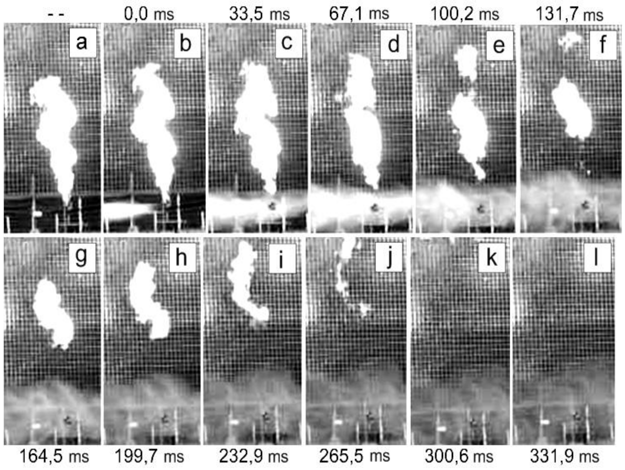

Fig. 6. Videogram of extinguishing of gas blow-out fire seat by impulse high-speed jet

Conclusion. The experimental researches of simulative gas blow-out fire seat extinguishing by means of high-speed liquid impulse jets generated by powder impulse hydro-cannon have been carried out. In the experiments by means of laser non-contact speed measuring device the speed of dropping liquid cross flow at which the extinguishing of simulative gas blow-out fire seat occurs, has been measured, as well as the aiming zone with the jet from impulse-type hydro-cannon that will cause the blow-out extinguishing has been defined. Maximum design speed of the impulse jet depending on charge energy ranged from 300 to 600 m/sec, that complies with the measured values.

Experimental research has shown that the speed of dropping liquid cross flow at which the extinguishing of simulative gas blow-out fire seat occurs is in the range of (80÷90) m/sec.

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Виноградов С.А. Использование импульсных высокоскоростных струй жидкости для тушения газовых фонтанов

Аннотация. Проведены экспериментальные исследования по тушению газового фонтана импульсными высокоскоростными струями жидкости, генерируемыми пороховой гидропушкой. Скорость струи в зависимости от порохового заряда колебалась от 300 до 600 м/сек. С помощью лазерной бесконтактной системы измерения скорости были проведены замеры скорости движения головы струи около пламени. Кроме этого, проведена скоростная видеосъемка процесса тушения факела. Установлено, что эффективное поперечное сечение высокоскоростной струи формируется на расстоянии 10-20 м от сопла гидропушки.

***Ключевые слова**: импульсная струя жидкости, пороховая гидропушка, газовый фонтан.*