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# Complex approach to implementation of filling emulsion explosives Ukrainit in underground conditions

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Abstract
Filling emulsion explosives are safe alternative to trotyl-containing materials. The paper objective is creation and implementation of complex approach to introduction of filling emulsion explosives with high explosion and technological parameters in underground mines of Ukraine. Compositions and technologies of production of filling emulsion explosives Ukrainit-PP-2 with controlled parameters of dispersion, viscosity, gas generation speed are developed. The small-size and self-propelled mixing and charging machinery for holes charging in drifting faces and blind drifts is developed and implemented. The advanced technology of formation and reliable holding of charges of emulsion explosives in vertical wells with a diameter more than 89 mm is tested. The self-propelled and block-modular mixing and charging machinery is developed for charging of drill ring of well from the mouth of face. The diagram of logistics and technical means of transportation of components of emulsion explosives from a surface in mine to the area of consumption is developed. The complex approach allows increasing efficiency and safety of explosive works in underground conditions and abandoning application of trotyl-containing explosives.
Key words: FILLING EMULSION EXPLOSIVES, TECHNOLOGY OF CHARGING, MIXING AND CHARGING MACHINERY, TRANSPORTATION

**Relevancy**

Emulsion explosives (EE) are safe alternative to trotyl-containing substances which are widely used when mining in underground conditions [1, 2].

However, introduction of emulsion explosives in case of underground ore extraction in Ukraine is significantly complicated. It is due to lack of domestic mixing and charging machinery and technology of formation blasthole and borehole charges in Ukraine, and also absence of technology of reliable holding of charge in upward and steeply inclined boreholes of big diameter (more than 89 mm) in world practice.

The paper objective is creation and implementation of complex approach to implementation of filling

emulsion explosives with high level of detonation and technological parameters in underground mines of Ukraine.

Achievement of objective assumes solution of the following interdependent tasks:

1. creation of emulsion explosives compounding, technology of their obtaining and sensitizing;
2. development of domestic mixing and charging machinery for holes charging and drill ring of wells;
3. creation of technology of formation and holding of charge in upward and steeply inclined boreholes of any diameter;
4. development and implementation of logistics of transportation of emulsion matrix of explosives from a surface.

At that, the complex of solution should consider all mining-and-geological and technological features of ore underground extraction in Ukraine.

The first step of introduction of filling emulsion explosives in underground conditions was the use of proven experience of emulsion explosives «Ukrainit-PP-2B» application in open mining operations of Ukraine [3]

- principally new method of sensitizing is use of water solution of inorganic peroxides as the gas-generating component (GGC), but not toxic nitrite sodium;
- possibility of "cold" gas generation and alkalescent nature of emulsion that provides the sufficient safety level of application in the sulphide-bearing rocks;
- absence of toxic products of explosion due to balance of composition and nearly 100% of completeness of all chemical reactions of decomposition of emulsion explosives. Formation of particles of calcium oxide and water vapors, which connect and settle possible polluting emissions, that is especially relevant for underground conditions;
- high speed of detonation (at least 5000 m/s) that provides intensive destruction of rocks of any level of hardness with high-quality crushing.

According to results of Ukraine first tests of filling EE in underground conditions in 2009 (holes charging in drifting faces of PJSC "Zaporizhzhia Iron Ore Plant"), the complex of research works on adaptation of EE composition Ukrainit to application conditions was initiated. Thus, the technology of driving operations assumes detonation of holes in 15-20 min after their charging. It required to increase the speed of gas generation of "cold" emulsion Ukrainit. The task was solved owing to introduction of the catalytic agent–hydrochloric acid to composition of the gas-generating component (Pat 82960 UA). It allowed not only increasing of gas generation speed to the required values, but also of EE detonation parameters. The hydrogen chloride in the system leads to formation at the initial moment of explosion of chloride nitrosonium ($NO_2Cl$), which accelerates thermal expansion of ammonium nitrate [4-5] and emulsions on its basis.

The main problem of charging of drill ring of well is holding of filling emulsion explosives in upward and steeply inclined boreholes. Experience of the leading foreign companies [6-8] including "ORICA" has shown that it is almost impossible to create and hold charge of emulsion explosives in wells with a diameter over 89 mm. At that in Ukraine, in the faces unsuitable for self-propelled technique, drilling is carried out by NKR machines (diameter of wells is up to 105 mm).

The solution of this problem is impossible without significant increase of viscosity of emulsion matrix of explosives. It required to change approach to technology of emulsifying. The device of static emulsifying which differs significantly from known one (Pat 69553 UA) was developed for obtaining high-viscosity emulsions. The device combines several controlled stages of emulsifying. Its application allowed obtaining emulsion compositions of specified viscosity and dispersibility that provided high power/weight ratio of emulsion in combination with scientifically based approach to selection of fuel phase [9].

Characteristics of filling EE Ukrainit-PP-2 for underground application are presented in Table 1. They are based on emulsions of two types: low-viscosity (type 1) and high-viscosity (type 2).

**Table 1.** Characteristics of filling emulsion explosives Ukrainit-PP-2

| Characteristic | Value | |
|---|---|---|
| | type 1 | type 2 |
| Density at a temperature (20±10)$^0$C in 1 hour after sampling, kg/m3 | 1050 – 1400 | |
| The gas generation level at a temperature (20±10)$^0$C in 30 min., %, minimum | 15 | 10 |

| | | |
|---|---|---|
| Fullness of detonation of charge in polymeric enclosure with a diameter of 50 mm from ammonite charge No 6ZhV weighing 100 g | FULL | |
| Oxygen balance, % (calc.) | – 0,18… -2,15 | |
| Warmth of explosion, kJ/kg (calc.) | 3000-3100 | 3100-3200 |
| Volume of explosion gases, l/kg (calc.) | 760-840 | 760-840 |
| Critical diameter of open charge, mm | 30-35 | 35-40 |
| Detonation speed in a steel shell with a diameter of 50 mm (at the density of 1250 kg/m$^3$), m/s | 5100-5400 | 5100-5300 |
| The minimum initiating pulse, the equivalent to ammonite No 6ZhV, g | 30 – 40 | |
| The relative working capacity in trotyl equivalent | 0,75-0,80 | |
| Toxic gases of explosion expressed in terms of CO, l/kg | up to 15 | up to 14 |
| Unit volume electrical resistance, Ohm·m, minimum | 760 | |
| Critical density at a temperature of (20±10) $^0$C, kg/m$^3$ | 1440 | 1415 |
| Water resistance of emulsion matrix during 24 hours, kg/sq.m, minimum | 0,5 | |

The developed filling EE Ukrainit-PP-2 for mechanical charging of blasthole and borehole charges possess high rates of safety, namely, form the minimum quantity of toxic gases of explosion, which are not sensitive to blast, friction and heating; that is exothermal expansion does not begin up to the temperature of 175$^0$C.

The task of development of small-size and self-propelled mixing and charging machinery for formation of blasthole charges was solved in the schematic diagram of dosing pump of original construction. Experts of "NTO Tekhnotron" (Zhovti Vody) have developed design of piston dosing pumps of "single" (Figure 1) and "double" action with hydraulic control and rigid mechanical linkage of the main pump of emulsion and dosing pump of gas-generating component supply with possibility of its smooth control (Patent 19784 UA). Such devices provide introduction of the gas-generating component (GGC) directly to emulsion at the output from the pump with high-quality mixing of components.

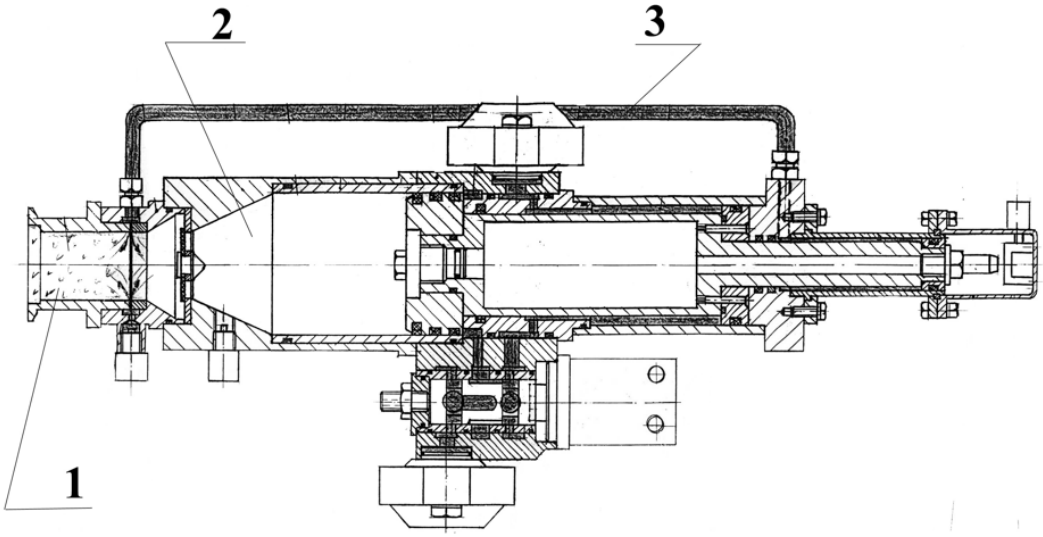


**Figure 1.** Dosing pump of "single" action 1 – output of ready-made emulsion explosives; 2 – supply of emulsion; 3 – supply of the gas-generating component

On the basis of dosing pumps of double action, experts of "NTO Tekhnotron", "Ukrvzryvtekhnologiya" and "ZZhRK" have developed and produced the first domestic samples of portable mixing and charging machinery of models SZS-1, ZEP-15 (Patent 62192 UA) of two modifications of ZEP-10 (Patent 67340 UA). This samples provide high-quality automatic dispensing and mixing of components with driven feed of obtained initial explosives in holes.

These chargers have successfully undergone comprehensive industrial tests under various gidro-, mining-and-geological conditions in mines: "Prohodcheskaya" and "Ekspluatatsionnaya" (JSC "Zaporizhzhia iron ore plant", Dniprorudne), "Nova" (LLC "VostokRuda" Zhovti Vody), PJSC "Kryvy Rih Iron Ore Plant", "Evraz Sukha Balka" (Kryvyi Rih), uranium mining plant SE "VostGOK" ( "Smolinska" and "Ingul" mines).

Further progress of experimental development directed to implementation of underground filling EE of Ukrainit allowed developing and implementation of self-propelled mixing and charging machine of model ZEVS-1 (Patent 82519). Charger of model ZEVS-1 has two-stage system of cleaning of waste gases, system of automatic fire suppression of running diesel, unit for chucks transportation and means of initiation in a basic configuration.

When maintenance of small sizes, two mixing and charging circuits are specified in design of self-propelled holes charger ZEVS-1. Circuits consist of two two-component dosing pumps of double action of original design ND-30. The implemented principle of well-balanced dosing allowed excluding of expensive proportional hydraulics and programmable electronics.

Unlike foreign analogs, in ZEVS-1 chargers, functioning of dosing pumps is provided not only by running diesel engine, but also by additionally set low-power engine. Such design solution provides reduction of expenditure of diesel fuel and emissions of waste gases that is extremely important for operations in blind drifts. The self-propelled charger ZEVS-1 is completely independent and does not require connection to mine pneumatic and electric circuits. Due to rather low cost, simplicity of service and small overall dimensions, self-propelled charger ZEVS-1 provides effective conduction of blasting operations in framings with section of 9-15 sq. m. and charging of 2-3 drifts per change. ZEVS-1 is successfully applied under conditions of PJSC "Zaporizhzhia iron ore plant".

The main characteristics of domestic mixing and charging technique for formation of blasthole charges with filling EE Ukrainit-PP-2 are presented in Table 2.

**Table 2.** Mixing and charging machinery for charging of holes with filling emulsion explosives Ukrainit PP-2

| Parameters | Model of mixing and charging machinery | | | |
|---|---|---|---|---|
| | SZS-1 | ZEP-15 | ZEP-10 | ZEVS-1 |
| Type of charger | portable | | | self-propelled |
| Productivity, kg/min. | 20,0-80,0 | 10,0-15,0 | 10,0-15,0 | 30,0x2=60,0 |
| Emulsion container volume, l | 7,0-150,0 | 15,0 | 20,0 | 360,0 |
| GGC container volume, l | up to 5,0 | 1,4 | 2,0 | up to 10,0 |
| Drive | Electrohydraulic / pneumatichydraulic | Water / pneumo | Pneumo | diesel-hydraulic |
| Dimensions, mm | 1100x1000x 1200 | 800x700x600 | 500x990x 850 | 4500x1900x2300 |
| Mass, kg | from 300,0 | up to 40,0 | from 37,0 | 3400,0 |

One of problems of EE charge formation in the upward wells is insufficiently fast gas generation of high-viscosity emulsions. For this problem solution, the process diagram of charge machines of the leading foreign companies surely includes the additional delivery line of special catalytic agent of decomposition of GGC. It complicates the process diagram and requires additional vessel and pumping equipment.

The task of increase of gas generation speed of viscous composition of EE Ukrainit-PP-2 was successfully solved by means of original construction nozzle which operation was studied in the special mixing and charging stand. This nozzle provides uniform mixing of emulsion and gas-generating additives with

increase in dispersibility and viscosity of finite emulsion explosive. The result is achieved due to the big shear loads emerging at the output from injector nozzle. It allowed to implement charging of drill ring of any diameter from mine face. Nozzle design provides arrangement of primed blasting cartridge on it for support of inverse initiation of explosive charge.

The conducted complex of design and experimental, research and development operations allowed developing the process flow diagram of mixing and charging machine for charging of drill ring of well in underground conditions. Against order of PJSC "Zaporizhzhia iron ore plant" according to the technical design specification developed by domestic experts of companies «Explominetech» (Germany) and "Ruda" (Poland), the mixing and charging machine RTCh-23 was designed and produced.

At the present time, RTCh-23 is successfully applied under conditions of «Ekspluatatsionnaya» mine (PJSC "Zaporizhzhia iron ore plant") including charging of the upward wells with diameter of 105 mm that has no analogs in world practice. According to results of explosion, high quality of crushing, absence of "boulders" and "overhang", small time of face airing are fixed.

For loading of emulsion explosive Ukrainit-PP-2 of drill ring of well in the drawing drifts, the technique, which provides use of low-viscous emulsion and locking devices of original design (TU 22.2-36373037-004:2014), was developed. Locking devices are equipped with the discharge chamber of supply of EE with ball-type valve and container where the insulating polymeric hole is located (in corrugated state). The container is provided with tube of compressed air supply for unrolling of insulating polymeric hole and its overturning along the well height.

In the course of charging, emulsion explosive, which is produced by means of the constructed mobile block and modular installation of UBM-1 model, moves via valves in well after installation of locking device at estimated distance from the mouth of well and unrolling of insulating hole. Application of developed technique allows mechanized charging of drill ring of well of any diameter from the mouth of face with low-viscous emulsion. Experience of application under conditions of «Ekspluatatsionnaya» mine (PJSC "Zaporizhzhia iron ore plant") has shown that the developed technique is most effective in case of high water inflow and significant destruction of walls of well. Technical characteristics of UBM-1 and RTCh-23 are given in Table 3.

**Table 3.** Technical characteristics of mixing and charging equipment for charging of drill ring of wells with filling emulsion explosive Ukrainit-PP-2

| Parameter | Block and modular installation UBM-1 | Mixing and charging machine RTCh-23 |
|---|---|---|
| Diameter of charged wells, mm | 89, 102, 105 | |
| Supplementary equipment for upward wells | locking devices | Special tamping plug or brush |
| The horizons on which loading of blocks is possible | travelling, subfloor | subfloor |
| Productivity, kg/min. | 50-80 (viscosity of up to 50 000 cP) | to 80 (viscosity of up to 180 000 cP) |
| Charging productivity (output per shift / monthly), t | up to 7,0 / up to 50,0 | over 8,0 / up to 110,0 |
| Engine power, kW | up to 4,0 | up to 112,0 |
| Emulsion / GGC container volume, l | 200,0 / 10,0 (refillable containers) | 3000,0 / 50,0 |
| Maximum dimensions LxWxH, mm | 750x450x500 o oil-pumping station 800x650x500 – pumping unit, 960x840x1100 – emulsion container | 9550x2000x2300 |
| Mass, kg | 60,0 + 90,0 + 65,0 = 215,0 | 21 100,0 |

Logistics is important aspect of problem of complex implementation of filling EE at underground operations. In parallel with development of mixing and charging equipment, schemes and technical means of delivery of EE components Ukrainit to the place of consumption were developed.

In 2009, the car-supplier VDEK-3 was developed for delivery of emulsion composition to the mine by rail transport. The car is used in mines of the main horizons equipped with a rail track of 750 mm. Charing of VDEK-3 is performed in superficial warehouse of explosives from suppliers of emulsion. Delivery of emulsion Ukrainit by the car-supplier from surface in mine is performed in cage, and then by mine electric locomotive in the rail workings in underground warehouses or distributing chambers. After carrying out tests and improvements, for the moment, 13 cars VDEK-3 are produced and put into operation in PJSC "Zaporizhzhia iron ore plant". In mine, the emulsion is unloaded from cars by means of the screw pump BN for mining workings in polytainers with volume of 30 l and is delivered in driving faces by self-propelled transport. In case of preparation of mass explosions in RTCh-23 and UBN-1, reservoir for emulsion composition of volume of 3 $m^3$ for direct delivery to places of charging is provided.

The cassette KEK-3m has been developed and produced for in-mine delivery of EE components on trackless workings. The cassette provides delivery of emulsion composition in mine to workplaces RTCh-23 and UBN-1 or accumulative containers of emulsion. Delivery of KEK-3m is carried out with use of self-propelled machine "Multimec 6600" of NORMET company. The cassette KEK-3m consists of the following parts: platform, containers for emulsion and gas-generating additives, hose chain, screw transporting pump, gauging rod, hydraulic stand. Technical characteristics of technical means of delivery of emulsion Ukrainit from a surface in mines are given in Table 4.

**Table 4.** Technical characteristics of technical means of delivery of emulsion explosives components Ukrainit-PP-2

| Characteristic | Delivery car VDEK-3 | Cassette KEK-3m |
|---|---|---|
| Transportation type in mines | rail | self-propelled machine |
| Supplied components | emulsion | emulsion / gas-generating additives |
| The mass of transported emulsion, kg | 4 000 | |
| Volume of containers in sections for GGC, l | - | 21*2 = 42 |
| Pump productivity, $m^3$/hour | - | to 10 |
| Total weight with load, kg | no more than 6000 | no more than 8000 |
| Overall dimensions, mm | length on buffers – 3950<br>width – 1350<br>height from a head of rail – 1600 | 3600x1500x1300 |

Implementation of integrated approach to introduction of safe filling EE Ukrainit-PP-2 allowed creation of domestic mixing and charging technique, technical means of delivery and advanced technologies of holes charging and drift ring of wells of any diameter. The complex approach allows increasing efficiency and safety of explosive works in underground conditions and abandoning application of trotyl-containing of explosives.

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