N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 3, Number 441 (2020), 40 – 47 **https://doi.org/10.32014/2020.2518-170X.52**

UDC 622.236.32

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INTENSIFICATION OF COMBUSTION FUEL MIXTURE IN PETROLAIR THERMAL TOOLS WITH EJECTOR NOZZLE

Abstract. The article considers the problem of increasing the power of the air-petrol thermal tools for destruction of rocks in the extraction and processing (stabilizing) block of stone, due to the intensification of combustion of the fuel mixture in a supersonic high-temperature jet torch burner. The model of shock wave excitation process in ejector nozzle, described by the equations of preservation of mechanics of continuous environments is given. As a result, the solution to this equation found the main operating and design parameters of the ejector nozzle, the parameters of the supersonic gas stream flowing from the Laval's nozzle of the burner into the cavity of the ejection nozzle, and the speed and temperature of the gas stream in the mixing chamber (combustion), the area of the output section and the diameter of the ejection of the mixing chamber, diameter and length of the free jet.

Key words: petrol-air thermal tool, supersonic high-temperature jet, heat flow, fuel components (gasoline, kerosene, air), detonation waves.

The intensification of combustion fuel mixture at the air-petrol thermal tools with ejector nozzle, made with perforations in the region of the initial section of the jet considered in the assumption of the creation on this site of powerful shock waves. Shock waves are formed when meeting with obstacle in a cylindrical nozzle (surface roughness ejected cold air) at the end of the supersonic gas jet from the nozzle of the main burner [1,2].

The supersonic jet carries particles of unburned fuel when the excess air ratio is equal to $\alpha_T = 0.5...0.7$, which, passing through the shock wave front, are burnt with high speed, forming a new high speed jet, thus greatly increasing the total energy capacity of the burner [3,4,5].

The conversion of chemical energy into heat and, simultaneously, to kinetic takes place in a cylindrical nozzle, which in this case is the combustion chamber. In the combustion cha mber is heterogeneous combustion (part of the components is in the liquid phase and the other in the gas phase), that is there are chemical and aero-thermodynamic processes in a moving reactive gas environment. In this case, the object of study of combustion may serve as the gas flow behind a strong shock wave. A peculiar form of burning in this case is detonation, which is characterized by extremely high velocities of combustion and a large local increase in pressure and temperature.

Model of the process of development of the detonation wave (shock wave) is described in domestic and foreign literature [6-12].

Let us consider the properties of planar shock fronts, which is widely used in one-dimensional models of the detonation wave. Common to all one-dimensional models are the representation of the detonation wave in the form of a complex consisting of the shock front and the adjacent reaction zone. Therefore, before proceeding to analyze the situation that occurs when supply chemical energy to the flow behind the shock front, we consider the laws that determine the properties of stationary shock waves in nonreactive environment.

Let us consider a planar shock front propagating at a steady velocity W_s. Pressure, density and velocity of the gas are denoted by ρ, p and u respectively. It is possible to simplify the analysis by transforming to a coordinate system with an origin fixed at the shock front to replace a laboratory frame of reference. The resulting flows are shown in figure 1.

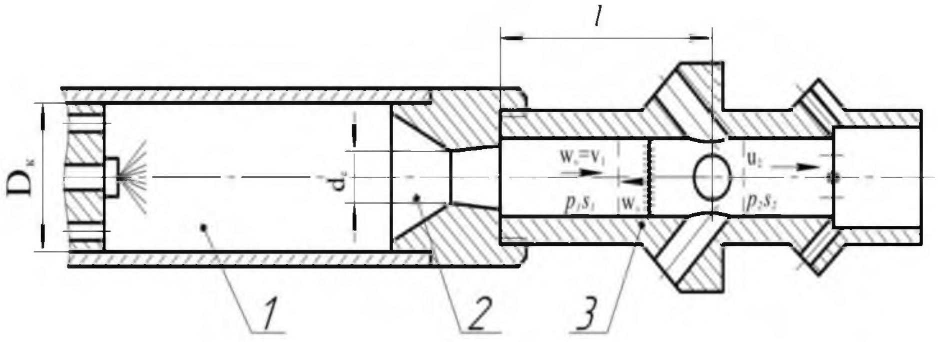


Figure 1 – Model of shock wave excitation process in the ejector nozzle
1 – combustion chamber; 2 – Laval's nozzle; 3 – ejector nozzle

Here the gas flows into the stationary shock front with a velocity W_s and emerges from the front with a velocity $u_2 = W_s - u'_2$, where u'_2 is the velocity of the gas relative to a stationary observer. Although the processes which occur in the vicinity of the shock front are irreversible, the three mechanical conservation conditions apply rigorously to the flows through the control surfaces.

In integral form they may be expressed as [6,11]

$$\rho_1 W_s = \rho_2 u_2 \text{ (conservation of mass);} \quad (1)$$

$$p_1 + \rho_1 W_s^2 = p_2 + \rho_2 u^2_2 \text{ (conservation of momentum);} \quad (2)$$

$$\rho W_s (h_1 + W^2_s/2) = \rho u_2 (h_2 + u^2_2/2) \text{ (conservation of energy),} \quad (3)$$

where $h=e+pV$ – is the specific enthalpy, e – is the internal energy and $V=1/\rho$ – is the specific volume. Furthermore, for the strengths of shocks typical of detonation, the ideal equation of state for a gas can generally be assumed to hold [8]:

$$p = \rho RT, \quad (4)$$

where R - is the gas constant, T – temperature.

Equations (1) - (4) have five unknown quantities, W_s, u_2, ρ_2, p_2, T_2, so that all the properties of the post-shock flow in region 2 can be expressed in terms of the velocity of the front and the initial conditions of the gas.

Equations (1) and (2) give an expression for the mass flow through the shock, p, thus:

$$(W_s \rho_1)^2 = (u_2 \rho_2)^2 = (p_2 - p_1) / (V_1 - V_2). \quad (5)$$

Equation (5) demonstrates that the mass flow into the shock is given by the square root of the negative slope of the straight line in the p-v plane which joins initial (1) and final (2) states. This line is termed the Rayleigh line. Equations (1) – (3) can be combined to produce [9]

$$h_2 - h_1 = (1/2)(p_2 - p_1)(V_1 + V_2)$$

or

$$e_2 - e_1 = (1/2)(p_2 + p_1)(V_1 - V_2). \quad (6)$$

Equation (6) is denoted the Rankine-Hugoniot.

It characterizes the initial and final states resulting from a given change in energy or enthalpy across the shock front. In other words, it is the counterpart of the relationship for isentropic and adiabatic processes [9]:

$$de = -pdV \text{ or } pV = const. \quad (7)$$

Equations (1) – (4) can be combined to yield pressure, density and temperature ratios across the front in terms of its Mach number, $M_s = W_s/a_1$, where a_1 is the speed of sound in the medium ahead of the shock:

$$p_2/p_1 = p_{21} = [2kM_s^2 - (k-1)] / (k+1); \tag{8}$$

$$\rho_2/\rho_1 = \rho_{21} = (k+1) M_s^2 / [(k-1) M_s^2 + 2]; \tag{9}$$

$$T_2/T_1 = T_{21} = -\frac{\left[kM_s^2 - (k-1)/2\right]\left[1 + (k-1)M_s^2/2\right]}{\left[(k+1)M_s^2/2\right]}, \tag{10}$$

where $k = \frac{c_p}{c_v}$ – is adiabatic index.

If the equation of species conservation (1) – (10) to write given the fact that in sections 1 and 2 thermodynamic parameters, structure and molecular weight of the mixture, the equation of the detonation adiabatic instead of 10 will look [10]

$$\frac{k_2+1}{k_2-1}p_2V_2 - \frac{k_1+1}{k_1-1}p_1V_1 - p_2V_1 + p_1V_2 = 2Q, \tag{11}$$

Finally, from the equation of state for section 2 will receive

$$T_2 = \frac{p_2V_2}{c_{v2}(k-1)}. \tag{12}$$

To increase the power of the jet gas stream carrying unburned fuel, it is necessary to introduce a jet of oxidizer is oxygen, so the ejector nozzle performed ejection bores.

The nozzle, formed by drilling ejection to ejection of the outer atmospheric air inside the nozzle promotes additional combustion of fuel components in the stream of oxygen ejection air. Nozzle and diffuser of the ejector are no different from ordinary nozzles and diffusers, the calculation of which is set out [8].

In determining the parameters of the ejector only significant coefficients of maintaining total gas pressure in these devices, the initial pressure of mixed gas, find the total pressure on the cut nozzles p_1^* and p_2^* and the full pressure of the mixture of p_3^* - total pressure at the exit of the diffuser p_4.. These coefficients are chosen according to the experimental data.

The main objective in the calculation of the ejector is to determine the parameters of the gas mixture at the outlet of the mixing chamber in the parameters of the gases before mixing.

Parameters ejection gas in the inlet section will be noted by index 1, the parameters ejection gas index 2, the parameters of the mixture in the outlet section - index 3. We assume given all the parameters of the flow in the inlet section of the chamber and build the solution so that from the equations of conservation of mass, energy and momentum flux to determine the temperature of braking, the velocity and total pressure of gas mixture in the outlet section of the chamber [8].

From the solution of the equations by the method [7,14] we obtain

$$\sqrt{(n+1)(1+n\theta+\nu)}z(\lambda_3) = z(\lambda_1) + n\sqrt{\theta}z(\lambda_2). \tag{13}$$

This equation is called the *main equation of the ejection*. According to the initial parameters of gases and ejection coefficient, it is possible to determine the gas-dynamic function $z(\lambda_3) = \lambda_3 + \frac{1}{\lambda_3}$, and given the speed of the mixture λ_3.

Knowing the parameters of the ejected and the ejected gases before mixing, we find a dimensionless value of n - ejection coefficient. This value can be expressed through the parameters of the flow in the inlet section of the chamber and is thus independent. Substituting into the expression for the coefficient of ejection of the magnitude of costs miscible gases, recorded with the help of relations (13), we obtain

$$n = \frac{G_2}{G_1} = \frac{p_2^* F_2 q(\lambda_2)\sqrt{T_1^*}}{p_1^* F_1 q(\lambda_1)\sqrt{T_2^*}}, \qquad (14)$$

or

$$n = \frac{1}{\Pi_0 \alpha \sqrt{\theta}} \frac{q(\lambda_2)}{q(\lambda_1)}. \qquad (15)$$

Equation (15) relates the coefficient of ejection n geometric parameter of the ejector α and parameters of the gases at the entrance to the chamber.

Further, it is necessary to experimentally find the temperature of the heat flow inside the nozzle, or the temperature of the inner wall of the ejector nozzle. To determine the temperature of the heat flow inside the nozzle must perform the inverse problem of heat conduction through a cylindrical wall that is slightly different for the determination of temperature at one and the same wall thickness of the cylindrical or flat [13].

To improve the energy parameters of gas-jet thermal tool proposes a new design of the working body with ejector nozzle and diffuser – a special nozzle for injecting atmospheric air).

Figure 1 presents a thermodynamic working body with ejector nozzle.

Relationships for calculation of achievable parameters and the optimum relationship of the cross sections of the gas-jet injectors (nozzles) can be derived based on the equations of the characteristics of these devices [14].

The result of the calculations obtained the main parameters of the ejection nozzle, when the ejection ratio $u = 4$, $P_p = 0{,}5$ МПа = 506625 h/m^2, $w = 1285$m/s, $T = 2020$ К (table).

Estimated data regime and design parameters of thermal tools with a nozzle at the cost of fuel components 17, 25, 35 l/hour

Regime and design parameters	17 l/hour, air 6 м^3/мin	25 l/hour, air 9 м^3/мin	35 l/hour, air 12 м^3/мin
The estimated performance of the injector G_c, *kg/sec*	0,4368	0,684	0,9428
Expense of a working stream G_p, *kg/sec*	0,1092	0,171	0,2357
Expense of the injected stream G_H, *kg/sec*	0,3276	0,513	0,7071
The critical section of the working nozzle d_{p*}, *mm*	20	22	26
The exit section of the ejector nozzle of the Laval's nozzle d_1, *mm*	24	30	36
Length of the free jet l_{c1}, *mm*	262,5	328,24	393,8
Diameter of the free jet d_2, *mm*	148,8	186	223,2

Figure 2 shows the schedule of change of a stream range of the thermal tool with ejector nozzle depending on consumption characteristics of fuel components.

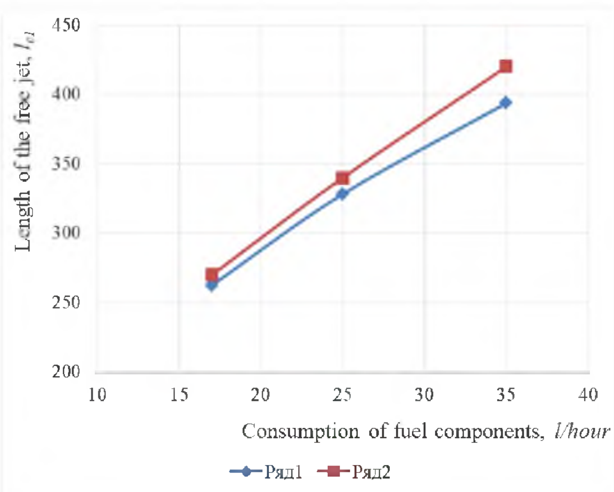


Figure 2 – The schedule of change of a stream range of the thermal tool with ejector nozzle depending on consumption characteristics of fuel components: 1 – theoretical, 2 – experimental data

Thus, the main parameters achievable compression pressure and the pressure in the inlet section of the mixing chamber and the main geometric dimensions of the gas-jet injector with diffuser – special nozzle for air injection.

We consider the case when the transfer of heat through a homogeneous and isotropic wall to one surface of the specified boundary conditions of the second kind in the form $q_c = const$ (at $x = 0$); on another surface is set to the heat-transfer coefficient α_2, and the ambient temperature $t_{жс2}$, i.e. boundary conditions of the third kind (figure 3). Internal sources in the wall are missing ($q_c = 0$).

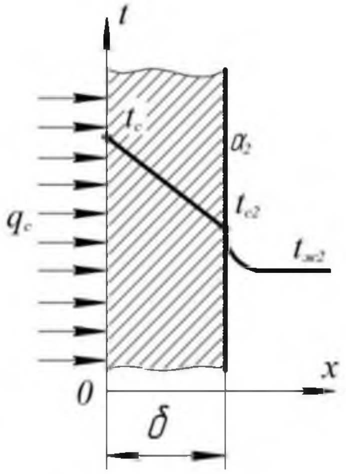


Figure 3 – The transfer of heat through a flat wall (mixed boundary conditions)

This problem is reduced to finding the temperature distribution in the wall and the temperatures on its surface. Because of the stationarity of the thermal regime we can write the following equation:

$$q_c = (t_{c1} - t_{c2})\frac{\lambda}{\delta}; \; q_c = \alpha_2 (t_{c2} - t_{жс2}). \tag{16}$$

From equations (16) it follows that for a given value of q_c

$$t_{c2} = t_{жс2} + q_c \frac{1}{\alpha_2}; \; t_{c1} = t_{жс2} + q_c \left(\frac{1}{\alpha_2} + \frac{\delta}{\lambda} \right). \tag{17}$$

We find from the formula (17) the temperature inside the ejection nozzle:

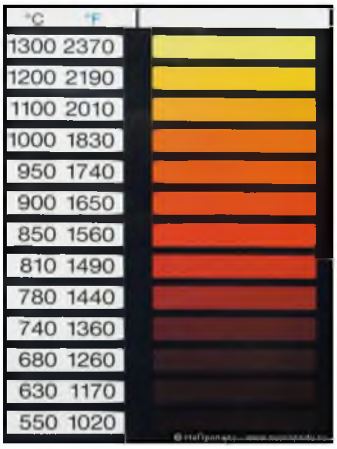
$$q_c = (t_{c1} - t_{c2})\frac{\lambda}{\delta}; \; q_c = \frac{\lambda t_{c1} - \lambda t_{c2}}{\delta}; \; \lambda t_{c1} - \lambda t_{c2} = q_c \delta; \; \lambda t_{c1} = q_c \delta + \lambda t_{c2};$$

$$t_{c1} = \frac{q_c \delta + \lambda t_{c2}}{\lambda}$$

where is λ – the heat transfer coefficient for metal, λ = 35 W/mK; δ – the thickness of the nozzle, δ = 5 mm = 0,005 m; q_c – the heat flow; t_{c2} – temperature , t_{c2} = 1473 K.

In accordance with figure 4 estimates the temperature of the metal by its colour temperature of the nozzle $T_н$ = 1100...1200^{0}C (1373…1473^{0}K) and given the increase in temperature of the working gas flow due to heat of combustion of unburned fuel, but with high temperature (2000^{0}C) and loss on heating of the metal nozzle, take the temperature of the mixed gas stream $T_н$ = 2000^{0}C.

a)



b)

Figure 4 – The comparative analysis of heating temperature of a surface
a thermal tool nozzle according to metal temperature on its color [15]:
a – process of the surface treatment of thermal tool with gasdynamic nozzle;
b – estimation of metal temperature nozzle on its color

Determine the temperature in the nozzle t_{c1} when various consumable fuel component (17 *L/h*, 25 *L/h*, 35 *L/h*). Get the temperature in the zone of intense combustion in the nozzle t_{c1} = 1854K.

Conclusions:

1. The model of shock wave excitation process in gas-dynamic nozzle is developed;
2. The gas flow flowing in the gas-dynamic nozzle is strictly subject to the three equations of solid media mechanics conservation: the equations of mass conservation, motion quantity and energy conservation;
3. The main ejection equation has been found, which allows to determine the main kinematic and structural parameters of the ejection nozzles, which allows to significantly increase the energy parameters of the thermal flow of a gasoline-air thermal tool;
4. To find the thermal parameters of gas treacle inside the nozzle - gas mixing chamber, an experimental method of determining the temperature of the outer surface of the nozzle from the table of metal beads colors was used;
5. To find the parameters of the thermal flow of gas in the nozzle, the inverse problem of heat conductivity for calculating the temperature of the inner surface of the nozzle for a flat wall has been solved;
6. As a result of calculation of a new design of a thermal tool with gas-dynamic, ejection nozzles, its main kinematic and structural parameters were obtained.

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ЭЖЕКЦИОНДЫ САПТАМАСЫ БАР БЕНЗИН-АУАЛЫ ТЕРМОҚҰРАЛДАРЫНДА ОТЫН ҚОСПАСЫНЫҢ ЖАНУЫН ИНТЕНСИФИКАЦИЯЛАУ

Аннотация. Мақалада термоқұрал жалынының дыбысты жоғары температуралы ағынында отын қоспасының жануын қарқындату арқылы блокты тасты өндіру және өңдеу (пассировкалау) кезінде тау жыныстарын бұзу үшін бензин-ауалы термоқұралдардың қуатын арттыру мәселесі қарастырылған. Тұтас орта механикасының сақталу теңдеулерімен сипатталған эжекциялы саптамада соққы толқынының өршу процесінің моделі келтірілген. Бұл теңдеуді шешу нәтижесінде эжекционды қондырманың негізгі режимдік және конструктивтік параметрлері табылды. Термоқұралдың Лаваль шүмегінен эжекционды қондырманың саңылауынан өтетін дыбысты газ ағынының параметрлері де табылды. Атап айтқанда, жану камерасындағы газ ағынының жылдамдығы мен температурасы, шығу қимасының ауданы және эжекционды қондырманың камерасындагы диаметрі, бос ағыстың диаметрі мен ұзындыгы табылды. Саптаманың ішіндегі жылу ағынының температурасы және саптаманың ішкі қабыргасының температурасы эксперименталды табылды. Қондырма ішіндегі жылу ағынының температурасын анықтау үшін цилиндрлік қабырга арқылы жылу өткізгіштіктің кері есебі орындалган, бұл цилиндрлік немесе жазық қондырма қабыргасының бір қалыңдыгы кезінде температураны анықтау бойынша ерекшеленеді. Металдың температурасы оның түсі бойынша багалау негізінде термоқұралдың қондырмасы бетінің қыздыру температурасының салыстырмалы талдауы келтірілген. Газ агынының температурасын анықтау үшін, металдың қызуын оның түсі бойынша температуралық бағалау бойынша саптаманың сыртқы қабыргасының температурасын анықтаймыз және содан кейін жылу өткізгіштік теңдеуді шешеміз, саптаманың ішкі қабыргасының температурасын немесе саптаманың газ ағынының температурасын табамыз. 17, 25, 35 л/сағ жанармай шыгындары кезінде газдинамикалық саптамасы бар термоқұралдардың режимдік және конструктивтік параметрлерінің есептік деректері және отын компоненттерінің шыгыс сипаттамаларына тәуелді жанаргы агысының алыс төзімділігінің өзгеру кестесі ұсынылган. Сонымен қатар бұл мақалада энергетикалық параметрлерді арттыру үшін инжекторы және диффузоры бар газ ағынды термоқұралының жаңа конструкциясы – атмосфералық ауаны инжектендіруге арналған арнайы қондырмасы ұсынылган. Араластыру камерасының кіріс қимасындағы қысу мен қысымның қолжетімді қысымының негізгі параметрлері, сондай-ақ диффузоры бар газ агынды инжектордың негізгі геометриялық өлшемдері (ауаны инжектендіруге арналган арнайы саптама) анықталды.

Түйін сөздер: бензин-ауалы термоқұралдар, дыбысты жогары температуралы агыс, жылу агыны, отын компоненттері (бензин, керосин, ауа), детонациялық толқындар.

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ИНТЕНСИФИКАЦИЯ ГОРЕНИЯ ТОПЛИВНОЙ СМЕСИ В БЕНЗОВОЗДУШНЫХ ТЕРМОИНСТРУМЕНТАХ С ЭЖЕКЦИОННЫМ НАСАДКОМ

Аннотация. В статье рассмотрена проблема повышения мощности бензовоздушных термоинструментов для разрушения горных пород при добыче и обработке блочного камня за счет интенсификация горения топливной смеси в сверхзвуковой высокотемпературной струе факела горелки. Приведена модель процесса возбуждения ударной волны в эжекционной насадке, описанная уравнениями сохранения механики сплошных сред. В результате решения этих уравнении найдены основные режимные и конструктивные параметры эжекционной насадки. Найдены параметры сверхзвукового газового потока, истекающего из сопла Лаваля горелки в полость эжекционной насадки. А именно: скорость и температура газового потока в камере смешения (сгорания); площадь выходного сечения; диаметр эжекционной камеры смешения; диаметр и длину свободной струи факела горелки. Экспериментально найдены температура теплового потока внутри насадки и температура внутренней стенки насадки. Для определения температуры теплового потока внутри насадки выполнена обратная задача теплопроводности через цилиндрическую стенку, что незначительно отличается по определению температуры при одной и той же толщине стенки цилиндрической или плоской насадки. Приведен сравнительный анализ температуры нагрева поверхности насадки термоинструмента по оценке температуры металла по его цвету. Для определения температуры газового потока внутри насадки по температурной оценке нагрева металла по его цвету определяем температуру наружный стенки насадки и затем, решая уравнение теплопроводности, находим температуру внутренней стенки насадка или температур газового потока в насадке. Представлены расчетные данные режимных и конструктивных параметров термоинструментов с газодинамической насадкой при расходах горючего 17, 25, 35 л/час и график изменения дальнобойности струи горелки в зависимости от расходных характеристик топливных компонентов. Также в данной статье для повышения энергетических параметров представлена новая конструкция газоструйного термоинструмента с инжектором и диффузором – специальной насадкой для инжектирования атмосферного воздуха). Определены основные параметры достижимого давления сжатия и давления во входном сечении камеры смешения, а также основные геометрические размеры газоструйного инжектора с диффузором – специальной насадки для инжектирования воздуха.

Ключевые слова: бензовоздушные термоинструменты, сверхзвуковая высокотемпературная струя, тепловой поток, топливные компоненты (бензин, керосин, воздух), детонационные волны.

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