

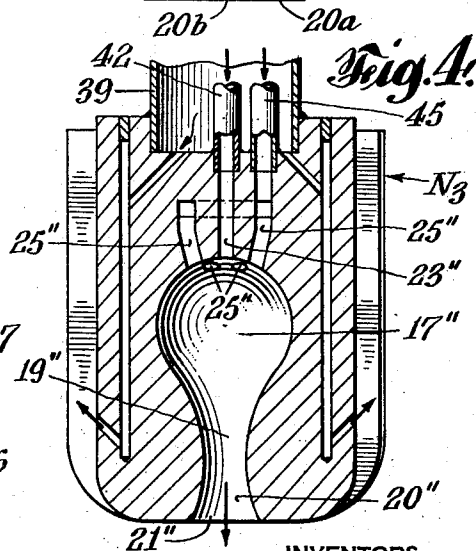
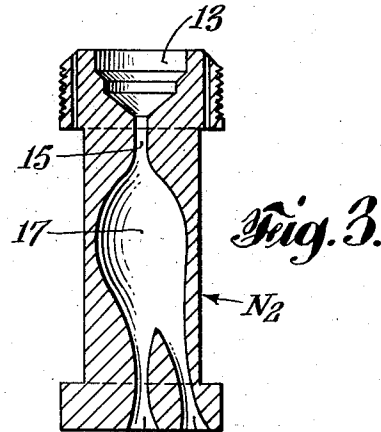
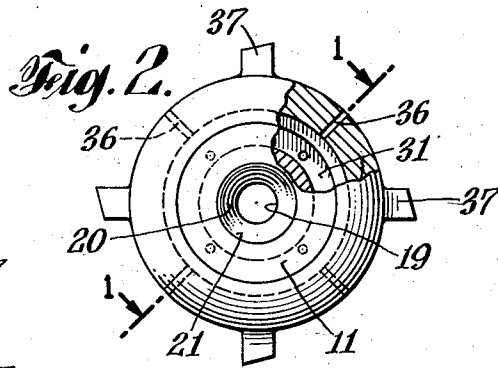
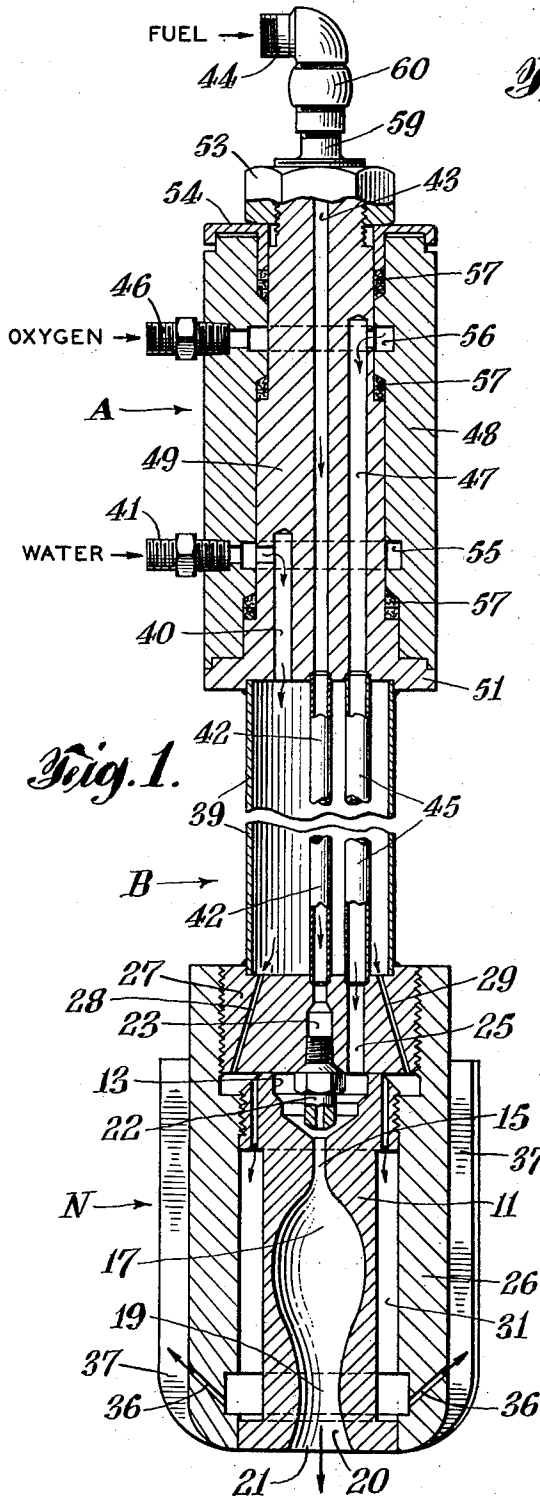
April 20, 1954

G. H. SMITH ET AL
METHOD AND APPARATUS FOR THERMALLY WORKING
MINERALS AND MINERAL-LIKE MATERIALS

2,675,993

Filed March 25, 1948

2 Sheets-Sheet 1



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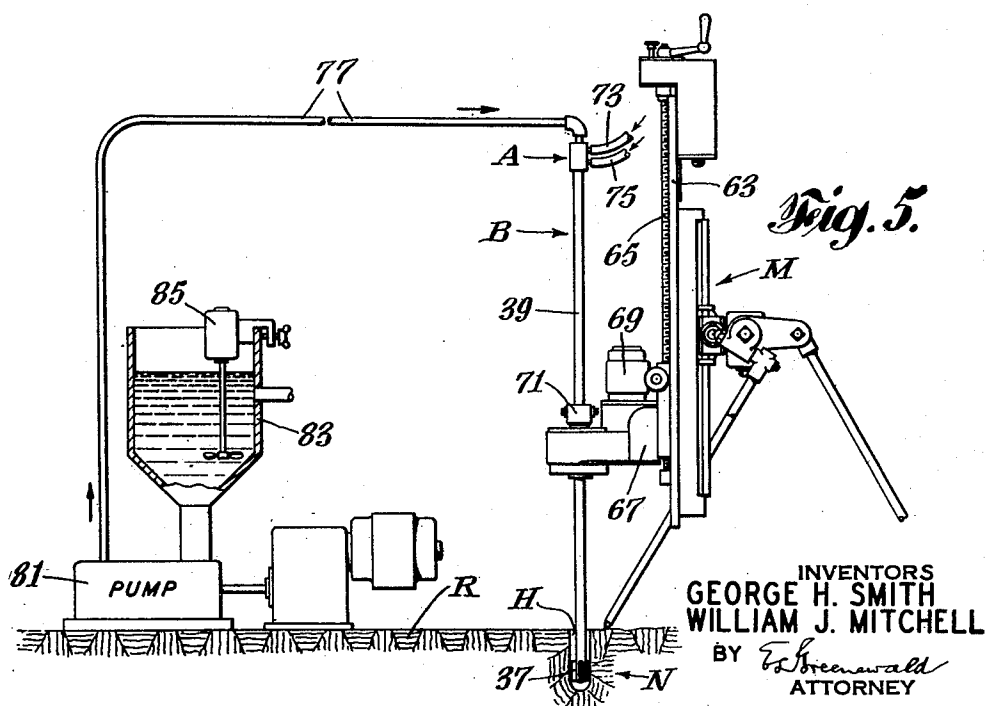
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UNITED STATES PATENT OFFICE

2,675,993

METHOD AND APPARATUS FOR THERMALLY WORKING MINERALS AND MINERAL-LIKE MATERIALS

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18 Claims. (Cl. 255—1.8)

1

This invention relates to a novel method of and apparatus for thermally working a mass of mineral or mineral-like material, and particularly relates to such a method and apparatus for piercing deep holes in such a mass.

Thermal piercing of holes in rock or like mineral materials was formerly practiced with a "post-mixed" or diffusion type oxy-fuel flame having relatively low jet linear velocity and heating intensity, formed by combustion of oxygen and fuel streams of relatively low velocity which both mix together and burn externally after discharge from a long blowpipe. Both gaseous fuels, such as acetylene, and liquid fuels, such as kerosene, were used successfully. Although the turbulence and inhomogeneity of such post-mixed flames make it impossible to measure the jet linear velocities accurately, they are always slower than 700 feet per second and generally slower than 300 feet per second.

In the relatively rapid and economical spalling process for piercing rock, a heat-spallable rock such as quartzite, dolomite, quartz, or chert is thermally pierced solely by the spalling off of small particles without melting, but this procedure has heretofore been limited to relatively few rocks because most minerals tend to melt in the heat of the post-mixed flame. Furthermore, when seams of non-spallable material such as clay are distributed in the body of spallable rock, the piercing operation must be arrested while the seam is penetrated mechanically. There are some other rocks, such as granite, from which material tends to spall off without melting, but which cannot be pierced solely by spalling with a post-mixed flame because some particles only partially separate from the mass and then fuse in position on the bottom of the hole, where they prevent the spalling of additional material.

Other rocks, such as taconite iron ore, have tended to melt in the heat of the post-mixed oxy-fuel flame. Taconite describes the stratified hard rock of the Biwabick iron formation of the Mesabi Range, and includes all rock of the formation except the rich ores. Piercing in such rocks has been accomplished by melting the material in the flame of a blowpipe, quenching the molten slag in the hole with water, and then mechanically disintegrating the quenched slag by physical impact with rotating teeth carried on the blowpipe. In this procedure it has been usual to employ a flux to fluidify the slag and to make it more friable when quenched. Although deep holes have been successfully pierced by this

2

procedure, the flux has materially added to the cost of piercing and it has not always been possible to pierce deep holes continuously and rapidly in a downward direction through strata of varied composition. Also, fluxes are inconvenient to handle and there is no single flux which operates with maximum efficiency on all types of rock encountered.

The speed of thermal hole piercing in taconite iron ore by the above procedure ranged between 1 and 2.4 inches per minute for holes about seven inches in diameter, whereas conventional churn drilling proceeded at between 0.2 and 0.4 inch per minute for about nine inch holes. The cost per foot of hole depth was approximately the same for both procedures.

In post-mixed flame blowpipes formerly used for performing the procedures described briefly above, separate acetylene and oxygen passages extend to the outer face of the tip of the blowpipe, and their relatively small discharge orifices tend to become partially closed or distorted both by striking the rock surface, and by the impingement of flying rock particles against the tip.

Among the objects of the present invention is to provide a novel method for thermally piercing or otherwise working a mass of rock by spalling and/or melting more rapidly and more economically than has been possible heretofore. Other objects are to provide such a method whereby: deep holes can be successfully pierced in a downward direction; piercing can proceed without a flux in more types of rocks than heretofore; piercing is continuous because the flame will not be extinguished by accumulated water; more varieties of rock can be pierced by the spalling process than heretofore; heat-spallable rocks can be pierced continuously even where seams of meltable material are encountered; and a relatively inexpensive fuel can be used. Another object is to provide such a method which is effective to pierce predominantly by spalling even those minerals which tend to melt. Still another object is to provide such a novel method which is effective for thermally piercing holes in any direction in hard iron ore bodies more rapidly and economically than heretofore.

Other objects of the invention are to provide a novel blowpipe construction which is less apt to be damaged by striking the bottom of a hole than former blowpipes; which will continue to burn even though water may accumulate in the bottom of a hole; and which provides a flame

3

having unusually high velocity and improved heating ability.

The above and other objects, and the novel features of the invention, will become apparent from the following description, having reference to the accompanying drawings, wherein:

Fig. 1 is a vertical sectional view of a novel blowpipe for performing the method of the invention, taken along the line I—I in Fig. 2;

Fig. 2 is an end elevational view of the blowpipe of Fig. 1 as seen from the bottom;

Figs. 3 and 4 are fragmentary vertical sectional views of alternative forms of blowpipes within the invention; and

Fig. 5 is a schematic side elevational view, parts being broken away and in section, of an arrangement of apparatus for thermally piercing a downward hole in a mass of rock by the method of the invention.

In accordance with the present invention, there is provided a novel method for thermally working a mass of rock or rock-like material, as by piercing a hole in it, which comprises separating material from the mass by applying against the mass from an internal combustion burner an intensely hot oxy-fuel flame having a jet linear velocity greater than 2500 feet per second, removing the separated material from the mass, and continuously advancing the burner and flame along a selected path to separate and remove additional material from the mass along the path. When piercing a hole in a mass of rock, a shallow cavity is formed when the flame is first applied to the surface of the mass, and this cavity is deepened by progressively advancing the flame into the cavity and into successive portions thereof as formed, to separate and remove additional material.

It is especially advantageous to employ a flame jet of supersonic linear velocity. According to our calculations, the sonic velocity (velocity of sound) in an oxy-fuel flame is about 3400 feet per second at the temperature of about 4500° F. which is attained by the flame of an internal combustion burner when oxygen and fuel are supplied in the stoichiometric ratio of about 3.5 to 1, by weight. The flame is most effective when its velocity exceeds 4000 feet per second. The maximum velocity obtainable to date has been 10,000 feet per second.

Flame velocity in an internal combustion burner may be calculated from thrust measurements using the equation:

$$V = \frac{(F - a\Delta p)g}{W}$$

where:

F=thrust by burner from reaction of flame jet, in pounds

W=weight flow of oxygen plus fuel, in pounds per second

a=area of nozzle bore at exit, in square inches

Δp =gauge pressure in exit end of nozzle, in pounds per square inch

V=flame velocity, in feet per second

g=acceleration of gravity in feet per second (approximately 32.2)

The high flame temperature and jet linear flame velocity of the present invention can be obtained by burning a mixture of fuel and an oxidizing agent in a burner of the internal combustion type where combustion occurs in a cham-

4

ber within a nozzle, and the flaming combustion gases are discharged at high velocity from the combustion chamber to the outside of the nozzle through a passageway. For supersonic jet velocity the combustion pressure in the combustion chamber should be at least twice the atmospheric pressure. The novel process has been performed successfully with a mixture of kerosene and substantially pure oxygen, but these and other fuels and oxidizing agents can be used effectively in gaseous, liquid or solid condition and in various states of purity.

Wherever pressure is referred to in the following description, gauge pressure is meant.

As shown in Figs. 1 and 2 of the drawings, one internal combustion burner B suitable for performing the method of the invention comprises a burner nozzle N including a core 11 having a large diameter oxygen inlet bore 13 in its upper end tapering gradually downward to a restricted central injector throat 15 which forms an entrance into a relatively large bulbous combustion chamber 17. The walls of combustion chamber 17 in turn converge downwardly to an exit throat 19 remote from throat 15, and a discharge passage 20 flares downwardly from throat 19 without further restriction to a discharge orifice or exit 21 in the lower end of the nozzle.

Fuel, such as relatively inexpensive kerosene, is injected at a high pressure greater than 15 pounds per square inch through the first throat 15 into the combustion chamber 17 by an injector nozzle 22 which is threaded into a fuel supply duct 23 in an adaptor body 27 and projects into the inlet bore 13 in axial alignment with throat 15 and combustion chamber 17. An oxidizing agent such as gaseous oxygen is concurrently but separately delivered at a high pressure greater than 15 pounds per square inch to the inlet bore 13 through an eccentrically arranged oxygen supply duct 25 in adaptor 27. The fuel and oxygen mix intimately together in passing through throat 15, and the mixture burns vigorously in chamber 17 at a combustion pressure greater than 15 pounds per square inch, producing large volumes of flaming combustion gases which rush at high velocity through the discharge throat 19 and the flaring passage 20 to provide an axially directed flame jet having a temperature of approximately 4500° F. and a supersonic jet linear velocity. The flame will continue to burn even when plunged into water, as in a flooded hole; and the nozzle is less subject to functional damage by flying detritus and by impact against the bottom of the hole than are external combustion burners.

More in detail, core 11 of burner nozzle N is threaded into a tightly fitting disintegrator sleeve 26 which terminates at its lower end flush with the lower end of the core. At its upper end, sleeve 26 projects beyond core 11 and is threaded over adaptor body 27 to hold the upper end of the core tightly against the lower face of the adaptor body with a fluid-tight seal in such a position that injector nozzle 22 and oxygen duct 25 are both in register with the bore 13.

The nozzle N is cooled by water or other fluid coolant supplied through a pair of ducts 28 and 29 in body 27 to an annular header chamber 31 formed around core 11 between sleeve 26 and adaptor 27. Water leaves the nozzle through a group of circumferentially arranged upwardly and outwardly inclined ports 36 establishing

communication between the header chamber 31 and the outer surface of the sleeve close to the lower end of the nozzle. When piercing by melting, the water quenches the molten slag so that it can be disintegrated by physical impact. When piercing solely by spalling, the water dampens the unfused spallings to reduce dissemination of dust to the atmosphere. Steam formed by contact of the water with the hot material helps the gaseous products of combustion to eject detritus from the hole.

For assisting the piercing of a hole, as by breaking up any quenched slag by physical impact therewith and as by reaming the walls of the hole, radial teeth 37 extend longitudinally along the outside of sleeve 26 to its lower end. Several of the water discharge ports 36 are positioned between each pair of teeth.

Water is supplied to the ducts 28 and 29 in adaptor 27 through a long sleeve 39 acting as a torque tube secured at its lower end to adaptor body 27, and at its upper end to an upper body A having a passage 40 establishing communication between the interior of sleeve 39 and a hose connection nipple 41.

Kerosene or other fluid fuel is supplied to duct 23 through a tube 42 which extends through sleeve 39 and is secured at its ends to the adaptor body 27 and the upper body A. A passage 43 extends between tube 42 and a hose connection nipple 44 on body A.

Oxygen passes to duct 25 through a second tube 45 arranged within sleeve 39 alongside of tube 42 and secured at its ends to the adaptor body 27 and the body A. A passage 47 in body A carries oxygen to tube 45 from a hose connection nipple 46.

When piercing rocks by melting at least part of the material with the flame from nozzle N, quenching and solidifying the melted material with water from ports 36, and disintegrating the quenched material mechanically by physical impact with teeth 37, it is advantageous to rotate the teeth automatically as the burner advances to form successive portions of the hole. For this purpose, the upper body A is constructed with an external non-rotating barrel 48, and a core 49 is journaled within barrel 48 for rotation therein. It is to the lower end of core 49 that the sleeve 39 and tubes 42 and 45 are secured, so that they and the burner nozzle N all rotate with the core. Core 49 is held in barrel 48 by a flange 51 on its lower end, and by a nut 53 threaded over its upper end and bearing against a plate 54 on the top of the barrel.

Water is continuously supplied to sleeve 39 during its rotation by including an annular chamber 55 as a part of passage 40 between the core 49 and the barrel 48 so that the portions of the passage 40 in the core and barrel are always in register as the core rotates. An identical construction, using an annular passage 56, is employed for the passage 47 which supplies oxygen to tube 45 as the core rotates. Packings 57 of conventional design are provided between the core 49 and barrel 48 above and below the registering portions of passages 40 and 47, to prevent leakage.

Fuel passage 43 terminates at its upper end in a nipple 59 which is coupled to a conventional swing joint 60 designed to permit nipple 59 to rotate while kerosene is supplied continuously without leakage from the non-rotating hose connection nipple 44.

When using the described internal combustion burner for piercing a hole in rock, it is advantageous to operate it automatically with apparatus of the type shown in Fig. 5. The burner B is mounted in manipulating apparatus M which may be of the type described in detail in Reissue 22,964 granted January 20, 1948, to Charles J. Burch. Briefly, apparatus M comprises a support 63 having a feed screw 65 operable to move a carriage 67 along the support. Carriage 67 carries a motor 69 which rotates a chuck 71 clamped on the sleeve 39 of burner B, thereby rotating nozzle N, including teeth 37 as the burner advances with carriage 67 along the support.

Oxygen and water are supplied to burner B by hoses 73 and 75, respectively, leading from any suitable sources of supply. Fuel, such as kerosene, is pumped to the burner through hose 77 by a motor operated pump 81 delivering fuel to the hose from a reservoir 83. When a flux powder is suspended in the liquid fuel, the powder is prevented from settling out in reservoir 83 by a motor-operated agitator 85.

The drag of hoses 73 and 75 on the burner holds the barrel 48 of upper body A against rotation while the rest of the burner rotates with sleeve 39, and while the burner is advanced into a mass of rock R to form a hole H.

In a modified type of burner nozzle N₂ shown in Fig. 3, the construction is the same as described in connection with Fig. 1 except that two exits from a combustion chamber 17 are provided. The axis of one flaring discharge passage 20a is inclined downwardly away from the main longitudinal axis of the burner nozzle. As a result, the flame is discharged eccentrically and diverges from the main burner axis so as to sweep over an area of substantially greater diameter than the nozzle. The other flaring discharge passage 20b is arranged axially. With this arrangement the flames overlap, the diameter of the hole being pierced is increased over that obtainable when only a single flame is discharged centrally from the nozzle, and no projections or cores are left in the hole to impede the blowtorch.

In another type of burner nozzle N₃, shown in Fig. 4, the fuel and oxygen are discharged concurrently directly into a combustion chamber 17' without first passing through an injector throat. Kerosene or other fuel is introduced into chamber 17' through a central passage 23'; and oxygen is blown in through a group of ducts 25' arranged in a ring around passage 23' and inclined downwardly toward the axis of passage 23' so that the several oxygen jets atomize the fuel and mix intimately therewith. The gases of combustion then pass out through a discharge throat 19', a flaring passage 20'', and a discharge orifice 21'.

The high linear velocity and temperature of the flame, required by the method of the invention, can be obtained with the described internal combustion burners by properly proportioning the various sections of the internal nozzle passages, together with supplying the oxygen and fuel at the proper pressures and in the proper amounts and ratios.

The heating intensity of the flame and its dynamic jet action are dependent to a considerable extent upon the weight ratio of oxygen to fuel in the combustible mixture. This is shown by the following tables of results obtained from piercing holes in commercial zircon bricks (melting point about 2300° C.) solely by melting with-

a flame from a non-rotating internal combustion burner:

OXYGEN FLOW=6,000 CUBIC FEET PER HOUR

Kerosene, pounds per hour	Pounds O ₂ per pound Kerosene	Chamber Pressure, pounds per square inch	Piercing Rate, inches per minute
116	4.31	70	1.4
132	3.76	75	2.0
145	3.78	76	1.7
166	3.01	80	1.25
193	2.84	87	1.0
220	2.25	90	0.7

OXYGEN FLOW=9,000 CUBIC FEET PER HOUR

Kerosene, pounds per hour	Pounds O ₂ per pound Kerosene	Chamber Pressure, pounds per square inch	Piercing Rate, inches per minute
149	4.93	113	1.6
165	4.44	120	2.1
186	3.94	125	2.2
190	3.92	122	2.6
212	3.44	130	2.4
248	2.94	130	1.8
298	2.43	145	1.25
372	1.95	150	0

The internal combustion burner used in the foregoing tests on zircon brick was similar to that shown in Fig. 1, and had the following dimensions:

	Inches diameter
Injector throat 15	0.375
Combustion chamber 17	2.00
Discharge throat 19	0.625
Orifice 21	0.875

The importance of the weight ratio of oxygen to fuel is also shown by the following table of the results obtained in piercing holes about thirty feet deep vertically downward in a Minnesota taconite iron ore formation partially by spalling, and partially by melting the ore and then quenching and mechanically disintegrating it. The ore consisted of both spallable and non-spallable strata and was not uniform in composition for all tests. Flame jet velocities were between 5000 and 8000 feet per second.

Kerosene, pounds per hour	Oxygen, cubic feet per hour	Pounds O ₂ per pound Kerosene	Chamber Pressure, pounds per square inch	Hole Diameter, inches	Piercing Rate, inches per minute
215	9,000	3.5	125	9	5.04
270	9,930	3.05	160-175	8.5	5.12
280	10,000	2.97	115	8.7	4.5
270	9,650	2.96	170	9.2	4.46
280	9,650	2.87	170	9.8	4.66
200	6,000	2.50	78	9.2	2.94
295	8,100	2.28	145	9.2	2.36

The internal combustion burner used in the foregoing tests on taconite iron ore was similar to that shown in Fig. 1 but had two discharge passages leading from the combustion chamber as in the nozzle of Fig. 3. Its dimensions were as follows:

	Inches diameter
Injector throat 15	0.375
Combustion chamber 17	2.00
Discharge throat of first passage 20a	0.313
Discharge throat of second passage 20b	0.453
Discharge orifice of first passage 20a	0.444
Discharge orifice of second passage 20b	0.584

The data in the foregoing tables of results on zircon bricks and taconite iron ore show that the oxygen to kerosene ratio in pounds of oxygen per pound of kerosene should be between 2.25 and 5 to 1, with a preferred ratio of between 2.8 and 4.25 to 1, for greatest speed of piercing. These

ratios correspond to between 0.6 and 1.4 times the stoichiometric ratio for complete combustion of the fuel.

In the following specific examples, the effect of piercing various materials under different conditions is illustrated:

Example I.—In one example in which the required high flame temperature and velocity with the internal combustion burner of Figs. 1 and 2 were developed, kerosene was supplied at a pressure of 100 pounds per square inch and a rate of 60 pounds per hour to the injector 22; and oxygen was supplied at a pressure of 200 pounds per square inch and a rate of 2500 cubic feet per hour to the inlet 46. A combustion pressure in the chamber 17 just slightly less than 100 pounds per square inch was maintained. The dimensions were as follows:

	Inches
Injector throat 15	1/4
Combustion chamber 17	1 1/8
Discharge throat 19	3/8
Orifice 21	5/8

When combustion of the mixture was initiated within the chamber 17 and the flaming combustion gases were applied without flux to a mass of hard low grade taconite iron ore, a hole 2 inches in diameter and 3 feet deep was successfully pierced downwardly at a rate of 4 inches per minute while injecting water through ducts 36 and while rotating teeth 37. In contrast, using a burner of the diffusion type wherein oxygen and fuel were mixed after discharge, a maximum piercing rate of only 1.6 inches per minute was obtained on the same iron ore body even when a flux was used.

Example II.—In another example, kerosene was supplied to a larger internal combustion burner of the type shown in Fig. 4 at a rate of 165 pounds per hour and a pressure of 105 pounds per square inch; and oxygen was supplied at a pressure of 200 pounds per square inch and a rate of 7700 cubic feet per hour. A combustion pressure of 100 pounds per square inch in the internal combustion chamber 17' was obtained. The dimensions were as follows:

	Inches
Combustion chamber 17'	2
Discharge throat 19'	5/8
Orifice 21'	7/8

This larger burner pierced a hole 3 feet deep and 7 inches in diameter without flux by the method of the invention through a body of the same hard iron ore body at a rate of 2.8 inches per minute. Water again was injected into the hole while teeth 37 rotated.

An examination of the detritus expelled from both large and small holes of Examples I and II indicated that about 90 per cent of the detritus was separated from the rock mass solely by spalling without melting, and only about 10 per cent was first melted off and then quenched and mechanically disintegrated.

Example III.—In another example of how the process was performed, a hole 2 inches in diameter was successfully pierced solely by spalling material in the unfused condition from a mass of dolomite at the rate of 18 inches per minute, using the same flows and pressures of oxygen and kerosene as described above in Example I, and the same burner. Rotation of the burner was unnecessary. In contrast, an external combustion burner of the diffusion type was able to

pierce the same dolomite only at rates less than 3 inches per minute.

Example IV.—Under the same conditions as described in Example I, a hole 3 feet deep and 2 inches in diameter was pierced in a body of granite at a rate of 4 inches per minute solely by spalling, whereas an external combustion burner of the diffusion type operating in conjunction with a flux could not pierce the same material at more than 1½ inches per minute by melting, quenching, and mechanically disintegrating the granite.

Example V.—Under conditions similar to those of Example I, a mass of packed clay was pierced to a depth of 3 feet at a rate of 7 inches per minute with the internal combustion burner, whereas the external combustion burner was completely ineffective.

In Examples I to V the flame jet velocity was between 4500 and 6000 feet per second.

Other rocks which can be pierced solely by spalling by the method of the present invention are some taconite and magnetite types of iron ore formations, quartz, quartzite, chert, and trap rock. It has to date been impossible to pierce taconite iron ore, trap rock, granite, and dolomite to an appreciable depth solely by spalling when using the low velocity external combustion burners of the prior art.

The results of tests on the thermal piercing of holes 7 inches in diameter in Septeria taconite iron ore with different fuels in a blowtorch like that shown in Fig. 1 are tabulated below:

Fuel.....	Kerosene	Gasoline	No. 2 Fuel Oil
Hole depth, feet.....	31	15	31
Speed, inches per minute.....	3.8	3	3.7
Chamber pressure, pounds per square inch.....	145	150	118
Oxygen flow, cubic feet per hour.....	9,500	9,450	12,000
Fuel flow, pounds per hour.....	287	287	287

The test with gasoline was conducted by an inexperienced operator.

From all of the foregoing examples it is apparent that the present invention has greatly increased the speed of piercing many minerals. Not only is the speed increased, but the cost is greatly decreased.

A number of factors are believed to contribute to the improved results provided by the present invention. One factor is that the intensely hot combustion gases flowing at supersonic linear jet velocity heat the newly exposed rock surface at the bottom of a hole so rapidly that differential expansion of the surface rock with respect to the rock underneath is great enough and sudden enough to cause particles to spall off without fusing, even in rocks which heretofore could not be thermally worked by spalling. Rapid heating also is assisted by the heat developed upon compression of the high velocity gases when they strike the rock face.

Another factor is that the linear jet velocity of the combustion gases and their volume are so great that the gases by their dynamic action wash or erode off from the rock face at the bottom of a hole any partially loosened particles so rapidly as to expel loosened detritus from the hole before it can melt, thus making it possible to pierce solely by thermal spalling such rocks as granite and some iron ore formations which formerly could not be pierced in this manner. The eroding action increases as the square

of the velocity, so that the eroding action of the flames of the present invention is between about seventy and about one thousand times greater than the eroding action of previously known rock piercing flames.

Both the above two factors also cooperate for piercing other iron ore formations predominantly by thermal spalling and only to a minor extent by melting, whereas formerly they could be pierced only by melting. Furthermore, even when a large amount of melting occurs, the high velocity gases sweep away the molten material so rapidly that only a thin film of molten material is maintained on the rock face at the bottom of a hole.

A third factor of importance is the blasting effect on the rock of supersonic vibrations, and shock waves or compression shocks which are developed by the internal combustion burner under the operating conditions described in the several examples. Supersonic vibrations of the order of 25,000 cycles per second are developed and occasionally may reach 100,000 cycles per second. Shock waves, which are similar to a series of closely spaced explosions, develop inside the burner nozzle and leave the nozzle as waves or pulsations in the flame having a series of extremely high velocities and pressures which cause rock particles to separate from a rock mass entirely or predominantly by the spalling of particles therefrom, without melting. The existence of these shock waves is shown by the closely spaced Mach waves which can be observed in the flame itself as it leaves the burner nozzle and by the terrific noise caused by the rapidly recurring explosions.

In a sense the flame of the present invention may be described as burning as a sustained flashback which is controlled as to location, and is prevented from damaging the blowtorch by the construction of the burner nozzle and the use of a fluid coolant. It is as resistant to the recession of flame into the fluid supply passages as are conventional external combustion diffusion flame burners, and is more resistant than are conventional external combustion pre-mixed flame burners.

Specific examples have been described above to illustrate the principles of the invention. It is to be understood that the invention is not limited to the features specifically described but that changes can be made in the construction and arrangement of parts in the burners, and in the steps of the method.

We claim:

1. A method of thermally working a mass of rock which comprises separating material from said mass by applying against said mass a flame having a jet linear velocity greater than 2500 feet per second, removing the separated material, and advancing said flame along a selected path to separate additional material from said mass along said path.

2. A method of thermally piercing a hole in a body of rock which comprises progressively separating material from said body by applying thereto from an internal combustion burner a flame having a jet linear velocity greater than 2500 feet per second, removing the separated material from said body thereby leaving a cavity therein, and advancing said burner and flame into said cavity to deepen said cavity by separating and removing additional material.

3. A method according to claim 2 wherein said flame is an oxy-liquid fuel flame.

4. A method according to claim 2 wherein said flame has a velocity greater than 3400 feet per second.

5. A method according to claim 2 wherein at least part of said flame is directed eccentrically from said burner, and said burner is rotated during its advance.

6. A method of thermally piercing a hole in a body of rock which comprises progressively separating material from said body by applying thereto from an internal combustion burner an oxy-fuel flame resulting from combustion of oxygen and fluid fuel in a weight ratio of between 0.6 and 1.4 times the stoichiometric ratio for complete combustion, said flame having a jet linear velocity greater than 2500 feet per second, removing the separated material from said body thereby leaving a cavity therein, and advancing said burner and flame into said cavity to deepen said cavity by separating and removing additional material.

7. A method of thermally working a mass of rock which comprises introducing an oxidizing agent and fuel into an enclosed combustion space in a burner; burning said mixture in said space; discharging the resulting flame, including the gaseous products of combustion, from said space first through a throat and then through an expanding passage at a supersonic velocity; separating material from said mass by applying said flame against said mass; removing the separated material from said mass; and advancing said burner along a selected path to separate and remove additional material from said mass along said path.

8. A method of thermally working a mass of a rock such as granite of the type which cannot be thermally worked solely by spalling with a relatively low velocity flame from an external combustion type burner due to the partial separation and subsequently fusion of some particles, said method comprising thermally working said mass solely by spalling, without fusion, by applying against said mass from an internal combustion burner a flame having a jet linear velocity greater than 2500 feet per second, and removing the separated spallings in the unfused condition.

9. A method of thermally working a mass of rock such as iron ore which can be worked with a relatively low velocity flame from an external combustion burner only by melting off material from said mass, said method comprising separating material from such a mass predominantly by spalling off particles in an unfused condition and only to a minor extent by melting off material, said working being accomplished by applying against said mass from an internal combustion burner a flame having a jet linear velocity greater than 2500 feet per second.

10. A method of thermally working a mass of rock such as iron ore which can be worked with a relatively low velocity flame from an external combustion burner only by melting off material from said mass, said method comprising separating material from said mass predominantly by spalling off particles in an unfused condition but also to a minor extent by melting off material to form a fluid slag, by applying against said mass from an internal combustion burner a flame having a velocity greater than 2500 feet per second; quenching the fluid slag; mechanically disintegrating the quenched slag; and removing the spalled particles and the disintegrated slag from the region of disintegration.

11. A method of thermally working a mass of rock, which method comprises separating material from said mass by applying against said mass a flame of supersonic velocity as a series of shock waves, removing the separated material from said mass, and advancing said flame along a selected path to separate and remove additional material from said mass along said path.

12. A rock piercing blowtorch comprising a hollow body having non-rotating fluid supply conduits; a member journaled for rotation relatively to said body and communicating with said supply conduits during such rotation; a burner nozzle having an internal combustion chamber and a flame discharge passage leading from said chamber; conduit means connecting said burner nozzle to said member whereby said nozzle, said conduit means and said member rotate as a unit relative to said body; and said nozzle having passage means for fluid coolant adjacent said combustion chamber in position for cooling the latter.

13. A rock piercing blowtorch comprising a body having inlets for fluid fuel and oxygen; conduit means extending from said body including separate conduits for said fuel and oxygen; and a burner nozzle of the internal combustion type carried by said conduit means on the end thereof remote from said body, said nozzle having an enclosed combustion chamber having an entrance portion within which substantially instantaneous mixing occurs and combustion is initiated, passage means for separately conducting fluid fuel and oxygen from said conduit means directly into said entrance portion of said chamber, and a flame discharge passage leading from said combustion chamber, said discharge passage comprising a throat and an exit flaring from said throat.

14. A rock piercing blowtorch in accordance with claim 13 wherein the walls of said entrance portion of said combustion chamber are shaped to form an injector throat.

15. A rock piercing blowtorch in accordance with claim 14 wherein said nozzle has an injector chamber and an injector in said chamber aligned with said injector throat; and wherein one of said separate conduits is in communication with said injector and the other is in communication with said injector chamber.

16. A blowtorch having a nozzle provided with an internal combustion chamber, means for supplying fuel and an oxidizing agent to said chamber, and a plurality of flame discharge passages leading from said chamber and having separate outlets for the discharge of flame therefrom, one of said passages extending axially of said nozzle and the other being inclined at an angle to the axis of said nozzle, each of said passages converging from said chamber to a throat and then expanding from said throat to said outlet thereof.

17. A method of thermally piercing a hole in a body of rock with an oxy-kerosene flame having a supersonic linear jet velocity and a temperature of the order of 4500° F. which comprises supplying to an internal combustion chamber of relatively large diameter oxygen and kerosene at a pressure greater than 15 pounds per square inch and in a ratio of between 2.25 and 5 pounds of oxygen per pound of kerosene; burning said kerosene with said oxygen in said chamber and forming flaming gaseous products of combustion having a temperature of the order of 4500° F.; discharging said flaming gaseous products of combustion as a stream from said chamber

13

through a passage of smaller diameter than said chamber; during the passage of said stream through said passage expanding said stream by an amount sufficient to effect an increase in velocity thereof to a value exceeding that of sound; and directing the resultant flame jet having supersonic velocity against said body of rock to pierce a hole therein.

18. In a method of thermally piercing a hole in a body of taconite iron ore by applying thereto a flame to separate material from said body, removing the separated material from said body thereby leaving a cavity therein, and advancing said flame into said cavity to deepen said cavity by separating and removing additional material, the improvement which comprises applying said flame from an internal combustion burner as an oxy-kerosene flame having a jet linear velocity greater than 2500 feet per second, said flame resulting from combustion of between 2.25 and 5 pounds of oxygen per pound of kerosene, and with said

14

high velocity flame so heating the newly exposed surfaces of taconite iron ore at the bottom of such hole that material is separated therefrom predominantly by spalling and only to a minor extent by melting.

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