

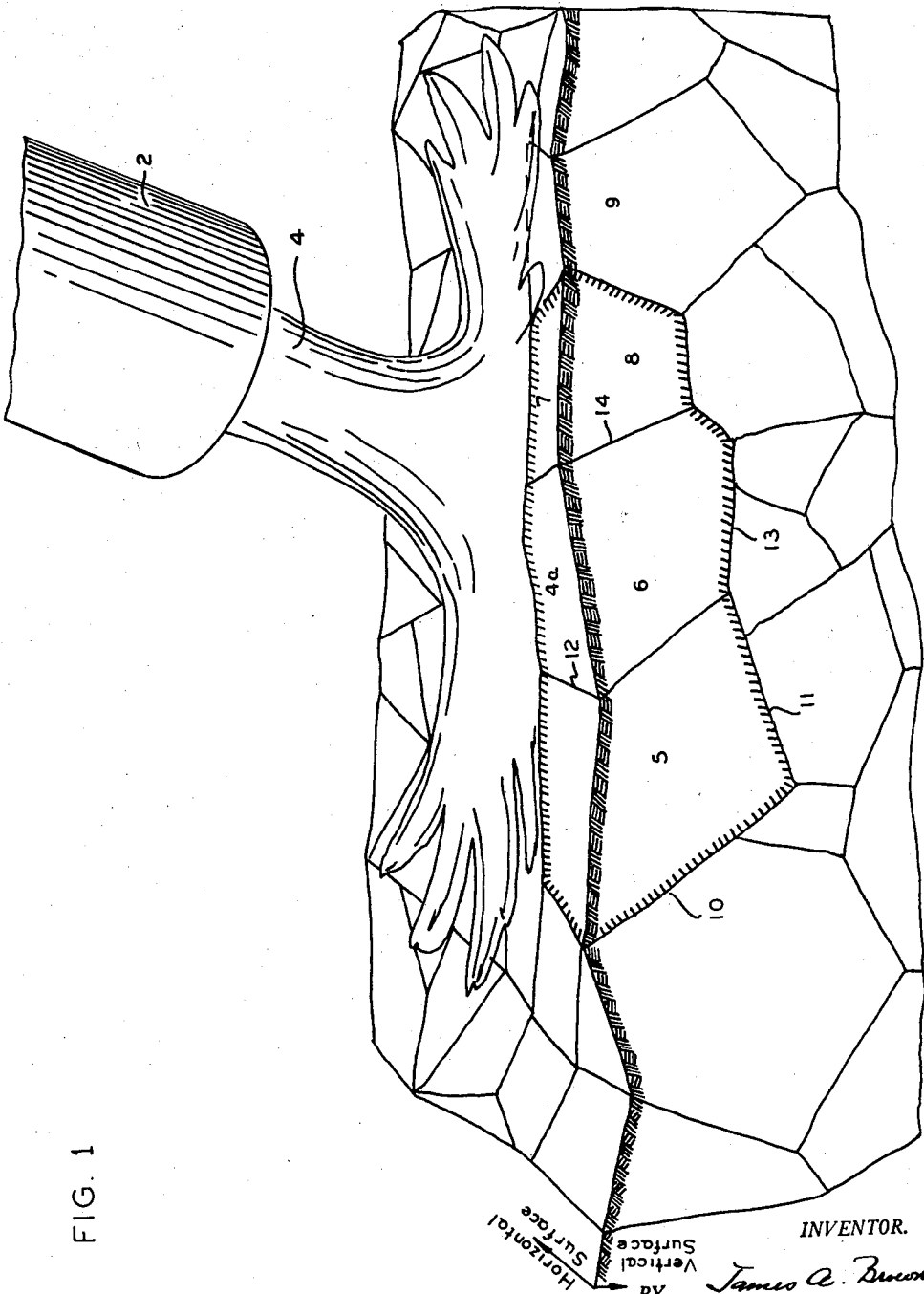
Sept. 10, 1963

J. A. BROWNING
FLAME CUTTING METHOD

3,103,251

Filed June 19, 1957

4 Sheets-Sheet 1



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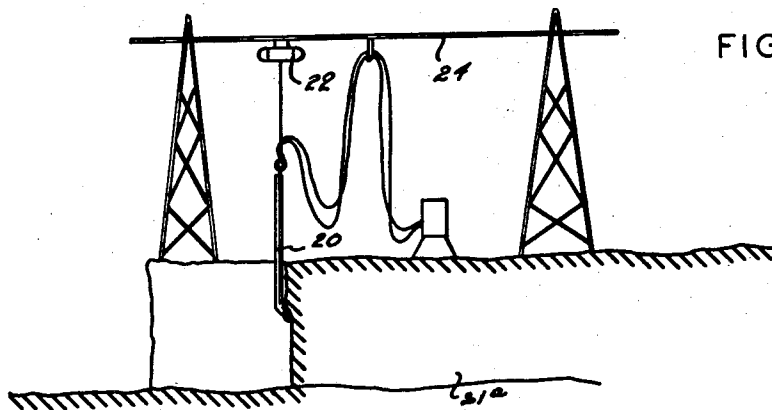


FIG. 2

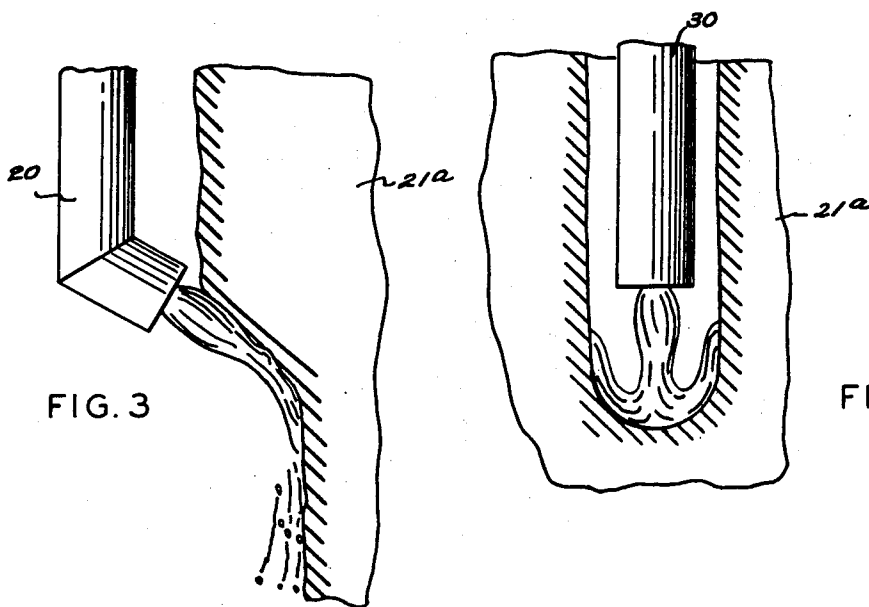


FIG. 3

FIG. 4

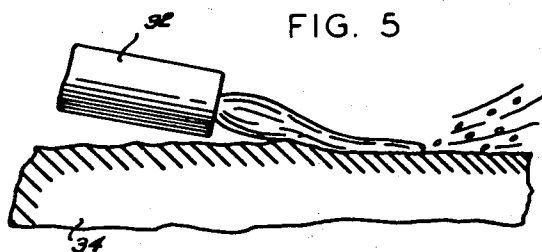


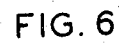
FIG. 5

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FLAME CUTTING METHOD

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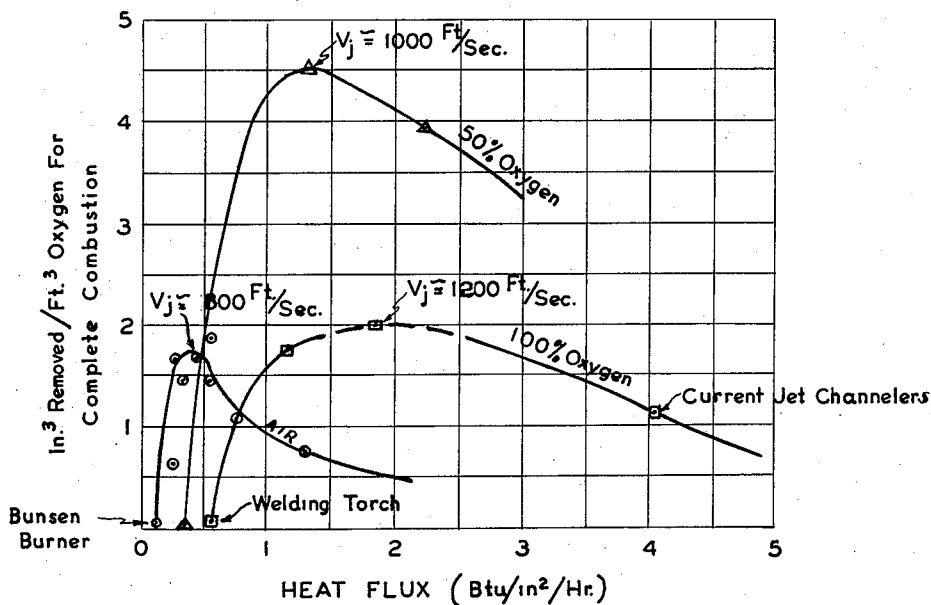


FIG. 9

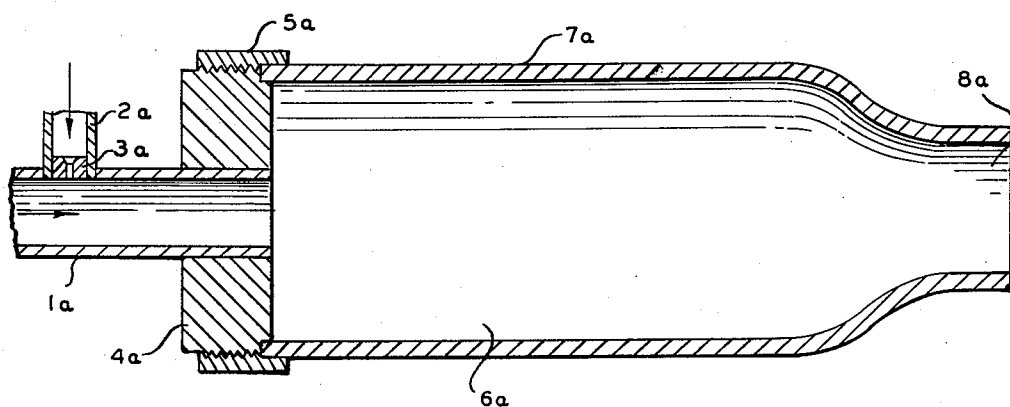


FIG. 10

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3,103,251

FLAME CUTTING METHOD

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5 Claims. (Cl. 175-14)

The present invention relates to methods and apparatus for flame working of materials, including such mineral bodies as granite, taconite, and other substances. This application is a continuation-in-part of my application, Serial No. 597,406 filed July 12, 1956, now abandoned.

The invention contemplates any type of flame working, including flame cutting, flame channelling, flame drilling, flame surfacing, and flame removal of naturally occurring mineral materials.

Flame working, in its broadest aspect, may be thought of as proceeding in two ways—one by means of an open flame having negligible momentum, the other by means of a jet flame characterized by relatively high momentum. The open flame is typified by such devices as the well-known oxy-acetylene torch. Such flames, due in large part to their negligible momentum characteristics, are not satisfactory for flame working mineral bodies for the reason that it is necessary to generate a certain minimum momentum in order to complete the separation of mineral particles from the mineral body. Open flames cannot be made effective by increasing their velocities because these velocities must be limited to a value less than that which results in flame extinction.

In a jet flame of relatively high momentum characteristics, with which the present invention is concerned, the stream of products of combustion is caused to issue from a confined space in which combustion has taken place. In other words, combustion occurs under superatmospheric pressure after which the jet flame issues from an orifice at very high velocity. This jet flame velocity, which is directly correlated with the pressure existing in the combustion chamber, furnishes high momentum characteristics of the flowing mass.

In flame working mineral bodies such as granite, as now commonly practiced, it has been a general assumption in the art that most efficient flame working is realized when utilizing jet flame velocities which are very high and which produce extremely high momentum, for example, velocities in excess of 3400 feet per second and temperatures in excess of 4500° F., utilizing an oil fuel with oxygen.

In the course of development work directed towards testing the validity of this general assumption, it has been observed that, in flame cutting certain mineral materials of the granite type with a relatively high energy flame of supersonic velocity characteristics, there is present objectionable noise and removal of material is accompanied by reduction of the removed material to a very fine state of subdivision or dust. This dust necessarily involves an excessive consumption of energy and it may produce an occupational hazard as well as being undesirable in other respects. It has been still further observed that the relatively high energy supersonic type flame, under certain conditions, may produce fusing in the mass of mineral material which operates to retard the rate of removal and thus lower the speed of cutting as well as resulting in an excessive energy consumption.

From a consideration of these undesirable factors, there has been conceived the idea of controlling the momentum and temperature characteristics of a jet flame of the oxy-fuel type and applying the jet flame to a mineral body in such a way as to provide for thermal stresses of limited intensity being induced in the mineral body.

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In line with this, I have discovered that superior flame working of a mineral body may be carried out by utilizing a jet flame whose momentum characteristics are derived from flame velocities occurring in a range above the velocity of an open flame and well below sonic speeds.

This is accomplished, according to the best form of the invention, by causing combustion in a combustion chamber to take place in the presence of an inert gas along with fuel and an oxidant such as oxygen, and conducting the inert gas which does not enter into combustion in the stream of products of combustion of the burned fuel into contact with the surface of a mineral body to provide for thermal stresses of limited intensity being induced in the mineral body.

The preferred oxidant is oxygen and the preferred inert gas is nitrogen. The proportions of nitrogen and oxygen may be as in atmospheric air. Some enrichment of air with oxygen may be desirable and, in general, the invention contemplates operation utilizing fuel, oxygen and the inert gas with proportions of oxygen and inert gas extending over the range from atmospheric air to nearly pure oxygen.

I have further discovered that the rate of removal of mineral material is increased greatly if a considerable amount of inert gas is supplied with the oxygen. In the case of granite, the maximum rate of removal occurs with about 50% oxygen and 50% nitrogen. With air, even though not enriched, removal efficiencies comparable to those obtainable with pure oxygen may be obtained. I also find that this increased rate of removal is accompanied by significant increase in the particle size of mineral particles which are removed.

Since the cost of the removal process is to a considerable extent dictated by the cost of the oxygen, it is also desirable to consider the process from the standpoint of amount of material removed per cubic foot of oxygen. On this basis, the 50% oxygen mixture is far more efficient than the pure oxygen, and even un-enriched air is better than pure oxygen.

As will be made apparent later, the reason for the benefits obtained by the presence of inert gas is that a subsonic jet flame may be obtained which has sufficient momentum to remove partially separated mineral particles without applying to the mineral body an inefficient excess of energy.

The present invention not only reduces the cost of operation and provides an improved removal rate, but also diminishes the hazards and nuisance of supersonic jet operations. A smaller portion of the mineral is reduced to respirable dust particles, and the noise is diminished to tolerable intensity.

These and other objects and novel features are illustrated in the accompanying drawings, in which:

FIG. 1 is a diagrammatic view showing in perspective a greatly enlarged section of a granite body wherein constituent particles have been represented as being joined together along irregular planes of joinder and, at the upper side of this mineral body, there is further indicated a flame cutting tool arranged to remove particles in accordance with the method of the invention;

FIG. 2 is another diagrammatic view indicating schematically a typical flame tool supporting apparatus for holding the flame tool in one desired working position in relation to a granite body;

FIG. 3 is a detailed fragmentary view of the cutting tool shown in FIG. 2 and indicating more specifically the area along which material may be removed in a channeling operation;

FIG. 4 is a detailed view of the cutting tool of the invention shown in the operation of drilling a hole in a body of granite;

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FIG. 5 is another detail view illustrating diagrammatically the step of applying a flame cutting tool to a body of granite to carry out a surfacing operation;

FIGS. 6, 7 and 8 consist of a set of comparative graphs illustrating, in the first instance, conventional cutting with a flame a granite free from discontinuities; in the second instance conventional cutting of granite with discontinuities occurring therein; and, in the third instance, cutting in accordance with the method of the invention, a granite having a discontinuity occurring therein;

FIG. 9 is a graph indicating results obtained in cutting granite at various flame velocities and heat fluxes; and

FIG. 10 is a cross-sectional view showing details of a flame cutting tool of the invention.

Referring more in detail to the method and the structures shown in the figures described, attention is directed to FIG. 1, in particular, wherein numeral 2 denotes the flame cutting apparatus of the invention which is shown in a suspended position such that a flame jet 4 is caused to impinge against a surface of the mineral body of granite or granite-like composition. The mineral body is made up of a multiplicity of mineral particles as 4a, 5, 6, 7, 8, 9, etc. These particles are joined together in a manner characteristic of granites and granite-like materials along discontinuous planes of joinder which have been indicated diagrammatically in FIG. 1 and denoted by numerals as 10, 11, 12, 13, 14, etc.

In accordance with the invention, I modify the conventional oxygen-fuel type flame jet to obtain the flame 4 of the invention and I apply this modified flame jet 4 in a selective manner to induce thermal stresses in the mineral body shown in FIG. 1, for example, so that there is produced differential expansion in the particles 3, 5, 6, 7, 8 and 9, and separation of these particles is caused to take place along some of the planes of joinder noted at the numerals 10, 11, 12, 13 and 14 without the individual particles being subjected to degradation either by way of disintegration or by fusing.

The preferred form of tool comprises the apparatus shown in FIG. 10 and comprises a tubular body 7a which defines the combustion chamber 6a.

Air supplied for combustion enters the burner through tube 1a. In this case No. 2 fuel oil is metered into the stream of air to form a combustible mixture. The oil is introduced through the metering orifice 3a from the tube 2a. Orifice 3a is designed to allow optimum fuel flow at the delivery pressure used. Tube 1a is supported to the combustor 7a by means of shoulder 4a and collar 5a. The mixture of air and fuel enters the combustion chamber 6a. Ignition is obtained by allowing only a small flow of fuel and air to issue unburned from the nozzle exit 8a. With flows adjusted correctly an auxiliary flame, or spark, causes these fluids to ignite beyond the exit 8a. The flame then flash-backs into the combustion chamber 6a. The air and fuel flows are then turned up to their desired values.

For the low combustion chamber pressures used (3-12 p.s.i. gauge) in practicing this invention it has been found that the chamber wall 7a need not be cooled by means other than radiation. However, in some cases it is desirable to supply additional cooling to wall 7a. One possible method of supplying such cooling effect is to allow the air for combustion to flow at high velocity over wall 7a before introduction to chamber 6a.

Combustion in nearly completed within the chamber 6a and the products produced issue through the nozzle exit 8a. The burner is designed to produce jet velocities within the range of this invention using standard fuel and air supplies.

The superior results of the present invention are shown by the curves of FIG. 9 which were obtained as a result of actual tests. In these curves, heat flux is plotted against efficiency. Heat flux is defined as B.t.u.'s per square inch of orifice area per hour, and efficiency is defined as cubic inches of mineral removed per cubic foot of oxygen neces-

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sary for complete combustion. In each case, the fuel was kerosene.

The first curve is for 100% oxygen. The usual jet channeller operates at the indicated point. At this point, the temperature is about 5400° F. and the velocity is about 4000 feet per second. The temperature is practically constant throughout the length of the curve, at least within about 200° F. It will be noted that a peak occurs at a velocity of about 1200 feet per second which is well below sonic velocity.

When 50% nitrogen is added to the oxygen, the second curve is obtained at which the temperature is about 4000° F. At this temperature sonic speed is about 3000 feet per second. A peak occurs at about 1000 feet per second at which most efficient operation occurs. There is a third curve for air, that is nitrogen and oxygen in approximate proportions of 79 and 21. For this curve sonic speed is about 2500 feet per second and the temperature along the curve is about 3000° F. A peak occurs at a velocity of 800 feet per second at which point the efficiency of removal is greater than that with the pure oxygen.

In comparing the air curve with the oxygen curve, it will be noted that the temperature is 3000° F. rather than 5400° F. and that the jet velocity is 800 feet per second as compared with about 4000 feet per second in standard operations. The efficiency, which is the volume of mineral removed per unit volume of oxygen, is greater with air than with oxygen. On an economic basis, more effective removal is obtained much more cheaply with air than with oxygen.

For higher rates of removal and for higher efficiencies, the air may be enriched with oxygen to give the 50% oxygen operation as shown by the optimal curve in FIG. 9. This has been found to be most effective for mineral bodies. For economic reasons, it may be preferable to use pure air because of the cost of the added oxygen.

The reasons for the superior efficiency of the present invention are believed to be as follows: A temperature gradient of sufficient intensity causes differential expansion of the heated mineral surface with relation to underlying layers. Internal stresses are created which lead to spalling of mineral particles and aggregates of such particles from the surface being heated. Many of these particles are not completely separated from the main mineral mass. These unseparated but loosened particles, which no longer can transfer heat to the main mineral mass, are rapidly heated under the action of the flame to the point where they fuse. Further cutting action ceases. In order to remove these partially separated particles, a certain amount of mechanical energy must be provided. If the energy were applied entirely in the form of heat, it would result merely in melting. A certain momentum is required to tear away the particles which have been loosened by the heat of the flame. In general, this momentum has been found to be greater than that which can be obtained by an open flame, and it is necessary to use a jet flame to obtain sufficient velocity. For an air-fuel flame jet a velocity of about 800 feet per second has been found adequate for most purposes. (It may be noted that the open flame maximum velocity for stable combustion of a fuel-air mixture would not give sufficient velocity to cause effective spalling.) Although a jet flame is necessary to produce adequate momentum for spalling, the excessive velocities obtained by the common jet channelers used in the art are of no greater effectiveness in their ability to remove partially separated particles.

For a given jet temperature, the greater the jet velocity the greater the heat transfer rate to the mineral mass. The temperature gradient associated with conventional oxy-fuel jet channelers is many-fold those of this invention. In present operations a large portion of the separated mass results from the shattering of individual particles to form dust. A lower temperature gradient produces less differential stressing of individual particles and

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allows for the spalling of a greater proportion of whole particles and aggregates of particles.

It has been found that for any one combination of oxygen to inert gas, optimum mineral removal rates are associated with that velocity which gives the minimum momentum value required to remove the partially separated particles. For the case of the air-fuel flame jet this velocity is about 800 feet per second, while for the oxy-fuel flame it is about 1200 feet per second. Momentum is the product of mass and velocity. The lower temperature of the air-fuel flame jet leads to a greater mass per unit of jet volume than in the case of the oxy-fuel flame jet. As the minimum momentum for effective particle removal would be expected to be the same in each case, the optimum velocity of the oxy-fuel flame jet is greater than that of its lower temperature counterpart. Although the addition of an inert gas to an oxy-fuel mixture reduces the flame temperature of the resulting jet, and thus its velocity, the momentum per unit of oxygen consumed is increased at a rate greater than the loss of jet velocity.

Thus, with supersonic velocities obtained with conventional oxy-fuel jets, the mineral is reduced to powder. This represents not only a wastage of energy, but it also creates a health hazard since a large proportion of the particles produced are of respirable size. Furthermore, a large part of the energy goes into enormous noise levels, which again are of no use for effective mineral operations and only create a nuisance in the neighborhood.

By the use of air which combusts with the fuel under a pressure to give jet velocities in the neighborhood of 800 feet per second, a peak efficiency of removal is obtained as shown by the air curve. Velocities lower or higher than 800 feet per second are somewhat less efficient, although satisfactory removal rates are obtained with velocities short of the sonic velocity, which in the case of air-fuel mixtures is about 2500 feet per second.

With air enriched to 50-50 oxygen-nitrogen mixture, the maximum efficiency is again obtained with velocities associated with those required to produce effective removal of spalls. It will be noted that the 50% oxygen curve operates most efficiently at a jet velocity of about 1000 feet per second. Satisfactory efficiencies are obtained for other values of heat flux, and it will be observed that the 50% curve is above the 100% oxygen curve over substantially its entire length.

The foregoing curves are illustrative only and are intended to represent that a peak exists for removal efficiency, and that effective operation occurs with oxygen diluted by a substantial quantity of inert gas so that the energies and velocities involved are such as to promote the desired mechanism of spalling without complete disintegration of the mineral.

In practice, the proportions of fuel to oxygen are determined to provide a substantially rich mixture but an excess of fuel is preferred which burns in atmospheric air to provide additional heat energy. The appropriate quantity of oxygen mixed with nitrogen is fed under pressure to the combustion chamber, and the fuel is also fed to the chamber. For maximum economy compressed air is used, and for higher cutting rates the air may be enriched with oxygen. The optimal velocity for the particular mixture is determined from curves like those of FIG. 9. As heretofore noted, the velocity is directly correlated with the pressure in the combustion chamber, and the correct pressure may be determined by application of well-known thermodynamic principles.

The preferred velocity is that which is given for the peak of the selected oxygen-nitrogen curve. Since the peak is fairly broad, some considerable latitude is permissible. In general, the invention contemplates the use of a jet flame (as contrasted from an open flame) with inert gas, and operating at velocities lower than sonic velocity, but higher than velocities attainable with open flames.

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In addition to fuels such as propane and kerosene, there may also be employed various petroleum derivatives and other fuels. Similarly, in some instances, it may be desired to use other oxidants such as fluorine or its compounds.

The superior cutting characteristics of the jet flame of the invention may be advantageously employed in any of the various cutting operations already outlined above and illustrated diagrammatically in FIGS. 2-5, inclusive. Thus, in FIGS. 2 and 3, I have illustrated a flame tool 20 which is supported in a vertically adjustable carrier 22 in turn received on a supporting structure 24. By means of this arrangement, a channel may be cut in a horizontal direction through a block of stone 21 to carry out desired quarrying operations. Preferably, the tool 20 is started at a bottom point on the granite face and gradually raised as it cuts by the adjustable carrier. In FIG. 4, a flame tool 30 is shown being employed to drill a round hole and, in FIG. 5, a flame tool 32 is shown being employed to carry out a surfacing operation of a block of granite 34.

In connection with operations such as channelling and drilling, the method of the invention is found to be surprisingly effective in overcoming a long standing problem arising when cutting a body of granite having a discontinuity such as often occurs in natural rock formations. A discontinuity such as a crack, seam, bed, or the like interferes seriously with conventional supersonic type flame cutting. The conventional supersonic flame, as it approaches such a discontinuity, is slowed up in its rate of cutting and the immediately adjacent flame worked surface tends to become plastic due to softening and fusion of some of the rock components, and spalling practically ceases. Even where some rock components do not soften, if the general matrix of the stone becomes plastic, an unsoftened particle is unable to set up mechanical stresses against the soft matrix and, therefore, cannot cause the strains necessary to produce spalling. Further progress in the rock in many instances, therefore, will require removal of the burner and the application of mechanical penetration of the discontinuity by conventional tools at increased expense and loss of time.

FIG. 6 shows diagrammatically a conventional supersonic type piercing or channelling flame penetrating a solid rock body which is free from discontinuity. Cutting takes place along the line A-A and, for comparison, FIG. 7 shows a similar flame penetrating a rock body which has a discontinuity D. In FIG. 6, the curve C indicates the relative temperature of the rock particles at increasing distances from the flame along the line of advance A-A, temperature being plotted against the ordinate B.

It will be noted that, in FIG. 6, the temperature gradient decreases rapidly and smoothly from the high temperature existing at the working surface.

In FIG. 7, the discontinuity retards conduction of heat across it and heat builds up between it and the working surface, so that the gradient becomes very flat (point C₂). At such a point, there is less heat differential between the particle in contact with the flame about to be removed and the adjacent rock body, so that the rate of spalling drops off.

If the heat impact of the flame is great enough to bring the flat point C₂ of the curve up to or above the softening temperature E of the rock, as suggested in FIG. 7, spalling ceases altogether, and further application of the flame merely contributes to further fusion of the mass.

The phenomenon described is very common in taconite and granite, especially when worked with conventional pure oxygen flames.

However, the flame of this invention greatly reduces these difficulties, as illustrated in FIG. 8. Although the general pattern of temperature gradients is the same as shown in FIGS. 6 and 7, the level of the temperature

curve is much lower. Consequently, the level of the flat part of the temperature curve C_2 is below the softening point of the rock E and softening does not occur. Although the rate of penetration of the flame of this invention is reduced as it approaches the discontinuity, because the temperature gradient becomes flatter, nevertheless, the rock remains hard enough for mechanical strains to be set up to allow spalling to continue.

In some cases, the flame of this invention will penetrate discontinuity with no difficulties at all and, in any case, it will approach much closer to the discontinuity before any difficulties occur.

The very great reduction in occurrences of dust when carrying out granite cutting with the subsonic flame of the invention is important, both from the standpoint of lower energy consumption and from another point of interest, namely, respirable dust. In connection with respirable dust aspects of the invention, two identical tests were run with two different flames. The first flame was produced in the conventional manner by a burner consuming pure oxygen with optimum fuel flow. This flame showed characteristic light emitting diamonds which are present only in flames occurring with a jet velocity at or above sonic velocity. The second flame was produced by a burner having an identical oxygen flow but furnished with an air component comprising approximately $2\frac{2}{3}$ times the flow of oxygen. Fuel flow was adjusted to an optimum for the two proportionate amounts of oxygen and air indicated. The resulting flame was characterized by a flame jet velocity well below sonic speed, as indicated by the absence of the light emitting diamonds and being judged to be approximately 2300 to 2400 feet per second.

The two tests, using the flames described, were run on similar blocks of Chelmsford Grey Granite having a flat honed surface which permitted accurate measure of cavities created by each of the two flames. Measurement of the volume of these cavities afforded an accurate evaluation of the useful work done by the flames in each instance.

The two tests were run for periods of five minutes for each flame, being conducted in a closed room of about 8,000 cubic feet volume. The room and its enclosed air were well cleared of dust before each test. Air samples were taken with a Bausch and Lomb instantaneous impinger prior to each test and showed the background dust to be negligible. During the five minutes of flame operation, the operator, in the customary manner, had pinned to his shoulder the collar of a liquid impinger type dust sampler. It was considered that this would produce an average sample of the air breathed by the operator during the test.

At the conclusion of the tests, it was in general apparent that the air added flame had created a substantially larger cavity, that the air added flame had operated with much less noise and, finally, the air added flame had created much less airborne dust. Similar tests were later repeated and precisely the same conditions were observed.

Recorded data of the various tests is as follows:

	Oxygen-fuel flame of prior art	Air plus oxygen flame of invention
Relative Oxygen Flow.....	15	15
Relative Air Flow.....	0	40
Relative Fuel Flow.....	30	80
Total Cavity Created, cc.....	640	1250
Air Volume Sampled, cu. ft.....	0.5	0.5
Dust Count, ¹ Million dust particles per cu. ft. of air.....	65	25

¹ Method of counting: Hemocytometer cell—light field.

It will be noted in the above data that, with an identical quantity of oxygen, the air-added flame accomplished almost twice as much work and created less than

half as much dust. To accomplish the same useful work, the air-added flame made only 20% as much dust.

Study of particle sizes showed that over 90% of the particles sampled by the impinger were under 10 microns in diameter. The desirable size of chips from a work standpoint in Chelmsford Granite is from $\frac{1}{8}$ -inch to $\frac{1}{2}$ -inch or greater in diameter, consistent with the apparent crystal and particle size of the components of the rock. It is apparent, therefore, that this dust count is a measure of unnecessary and undesirable waste of work. The reason for the substantial difference in performance between the two flames is considered to be due to the rate of heat input of the two flames.

The invention takes advantage of the fact that, in a mineral body of which granite is typical, the individual particles are mechanically relatively strong in relation to the planes of joinder between them.

The higher temperature of the oxy-fuel type flame of the prior art and the higher convection produced by the higher velocity, which sweeps away insulative boundary layers, both operate to produce a higher temperature gradient in a particular particle or crystal, and one side is sufficiently hotter than the other to cause it to disintegrate.

The cooler slower flame of this invention does not create so steep a gradient in the particle and it, therefore, does not disintegrate, but remains in place until the heat input does its work on the weaker planes of joinder, so that the particle is removed whole or as an aggregate of several particles.

From the standpoint of industrial hygiene, this invention offers a very significant advantage over previous practices in the reduction it accomplishes in respirable dust. Various authorities consider 5 to 10 million dust particles per cubic foot as the top acceptable limit of dust particles of this type where men work.

Although the impinger dust counts in the test above show that both types of flames exceeded the acceptable limit, this is due to the fact that the tests were conducted in a completely closed room and that build-up of airborne dust occurred. In practice, these flames are used either in the open air or in enclosures where dust exhaust will be provided. Tests of dust count made in the open air are very unsatisfactory from a quantitative basis due to wind currents that would occur and, therefore, test data made in open air is not given here. However, with the flame of this invention, open air dust counts indicated a lower dust level than the higher temperature velocity flame of conventional practice. At no time has a sample shown an extremely high dust count to which the flame operator would be exposed. On the other hand, open air dust counts made on conventional flames have at times shown dust counts at entirely unacceptable levels. Where the flame of this invention would be used in an enclosure, it is obvious that the provision for dust removal would be less of a problem than the removal of dust from conventional flames. The test dust count would indicate that dust removal from an enclosure would have to remove only about $\frac{1}{5}$ as much dust as would conventional high temperature velocity flames.

A further advantage of the flame of this invention from the standpoint of industrial hygiene is the reduction in noise. Conventional supersonic flames for rock working are extremely noisy, particularly in the high frequency ranges. Noise levels exceeding 130 decibels have been recorded at the operators stations of such flames. Authorities state that continuing exposure to such noise levels will produce deafness.

Experience with flames of this type shows that, as sonic velocity is approached, reached and passed, noise output increases very markedly. In fact, noise, together with the typical diamond pattern of light emission which appears in the flame, constitute the two most practical indications of the type of flame which an operator is ob-

taining. As an operator adjusts his burner prior to putting it to work, he will rely very heavily on the noise created to determine when he has reached the adjustment desired.

It is one of the virtues of the flame of this invention that the noise level of the burner is well below the noise output which results from a flame at or near sonic speed. Consequently, this flame offers a very great advantage from the standpoint of industrial hygiene.

From the foregoing description of my invention, it will be apparent that I have disclosed an improved method of flame cutting which is characterized by important control features in respect to the efficiency and physical aspects of the material removed in certain types of rock cutting operations. I have also devised a unique flame producing means which makes use of novel combinations of fuel and oxidants.

It is intended that the invention may be embodied in various other forms and modifications, as included within the scope of the appended claims.

Having thus described my invention, what I claim is:

1. In a method of flame working a heat spallable mineral body, the steps which include introducing into a confined chamber a mixture of fuel and an oxidizing component gas which includes an oxidant and an inert gas, burning the mixture of fuel and oxidizing component gas in the confined chamber while maintaining a chamber pressure at the point where the burning is initiated in the range of 3 to 12 pounds per square inch gauge, and releasing the products of combustion through an orifice to form a subsonic jet having a velocity of at least 800 feet per second and an appreciably reduced noise level as compared with a supersonic jet, continuously regulating the thermal intensity and momentum of the flame jet with measured amounts of the inert gas furnished as a component part of the flow of oxidant and occurring in an amount which is substantially equal to the percent of inert gas normally found in atmospheric air, and directing the flame jet into contact with an exposed surface of the said mineral body to induce a thermal gradient of substantially constant predetermined mineral stressing capability whereby a controlled spalling takes place.

2. In a method of flame working a heat spallable mineral body, the steps which include introducing into a confined chamber a mixture of fuel and an oxidizing component gas which includes an oxidant and an inert gas, burning the mixture of fuel and oxidizing component gas in the confined chamber while maintaining a chamber pressure at the point where the burning is initiated in the range of 3 to 12 pounds per square inch gauge, releasing the reaction products of the burning mixture through an orifice thereby to form a subsonic flame jet whose mass, velocity and temperature combine to provide a spalling characteristic, directing the flame jet into contact with the heat spallable mineral body, and continuously controlling the spalling characteristic of the flame jet including the lowering of its thermal intensity and increasing its velocity by utilizing a quantity of inert gas at least as great as the quantity of oxidizing component gas to maintain the temperature of the flame within an operating range of not more than about 4,000° F., and to increase the velocity

of the flame to at least 800 feet per second, utilizing the momentum of the jet to scour the spalls away from the area of impact of the jet, and progressively moving the jet into contact with areas cleared of spalls by said scouring action.

3. In a method of flame working a heat spallable mineral body, the steps which include introducing into a confined chamber a mixture of fuel, oxygen and an inert gas, burning the mixture of fuel and oxygen in the confined chamber while maintaining a chamber pressure at the point where the burning is initiated in the range of 3 to 12 pounds per square inch gauge, releasing the products of combustion with the inert gas through an orifice to form a subsonic flame jet having a velocity of at least 800 feet per second, the inert gas being supplied in a quantity at least as great as the quantity of oxygen and not materially greater than about 79% of the total gas to materially lower the temperature of flame jet and modify its mineral spalling characteristics, directing the jet against the mineral body to cause formation of spalls of substantial size, utilizing the momentum of the jet to scour the spalls away from the area of impact of the jet, and progressively moving the jet into contact with areas cleared of spalls by said scouring action.

4. In a method of flame working a heat spallable mineral body, the steps which include introducing into a confined chamber a mixture of fuel, oxygen and an inert gas, burning the mixture of fuel and oxygen in the confined chamber while maintaining a chamber pressure at the point where the burning is initiated in the range of 3 to 12 pounds per square inch gauge, releasing the products of combustion with the inert gas from the chamber to form a sub-sonic flame jet, the inert gas being supplied in a quantity at least as great as the quantity of oxygen and not materially greater than about 79% of the total gas to cause the jet to have a temperature lower than about 4,000° F. and a velocity of at least 800 feet per second, whereby the jet has a high momentum due to the mass of the inert gas, directing the jet against the mineral body to cause formation of spalls of substantial size, utilizing the momentum of the jet to scour the spalls away from the area of impact of the jet, and progressively moving the jet into contact with areas cleared of spalls by said scouring action.

5. A method of flame working a mineral body according to claim 4, in which the oxygen and inert gas are supplied together as atmospheric air.

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