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(54) FLOW ALLOCATION IN DRILL BITS

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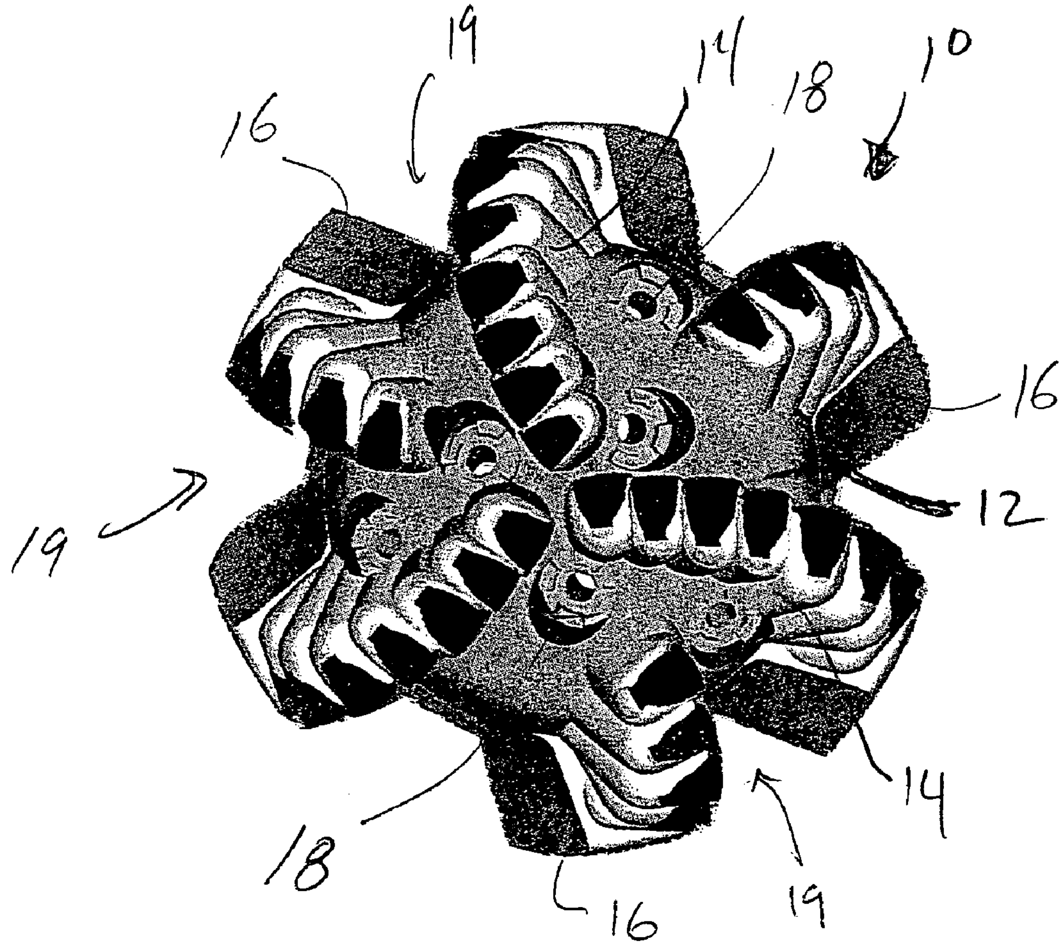
(57) **ABSTRACT**

A method for designing a drill bit comprising modeling a domain between a drill bit and a surrounding wellbore. A region is defined within each of a plurality of flow paths through which fluid travels through the domain. An allocation of flow among the plurality of flow paths through the domain is determined and the drill bit is modified such that the allocation of flow is substantially uniform among the plurality of flow paths. A drill bit comprises a bit body having a plurality of blades projecting there from, wherein at least one blade has a greater length than at least one other blade. A plurality of nozzles, or ports, are disposed on the body and a plurality of junk slots are formed between adjacent blades so that the flow of fluid through each of the plurality of junk slots is substantially uniform.



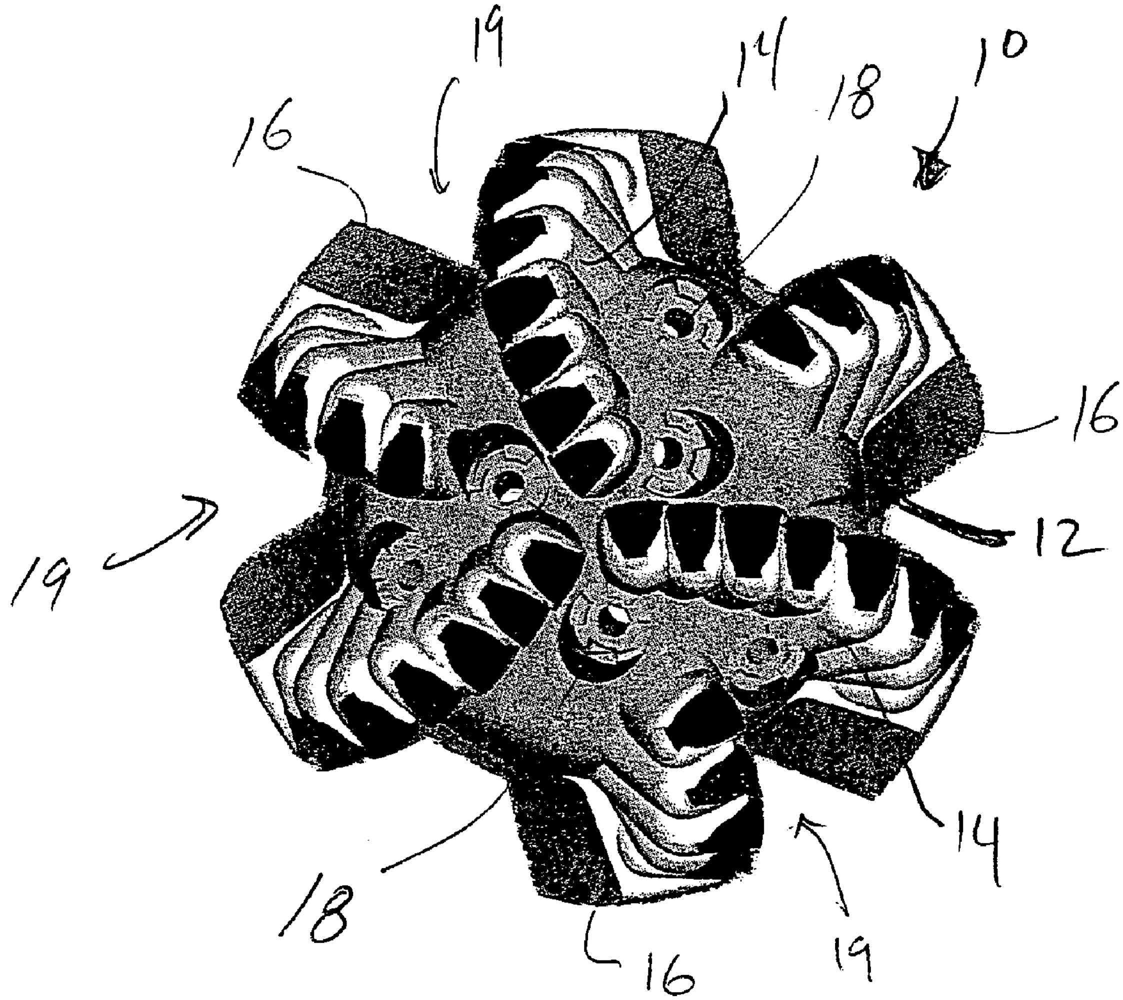


Fig 1

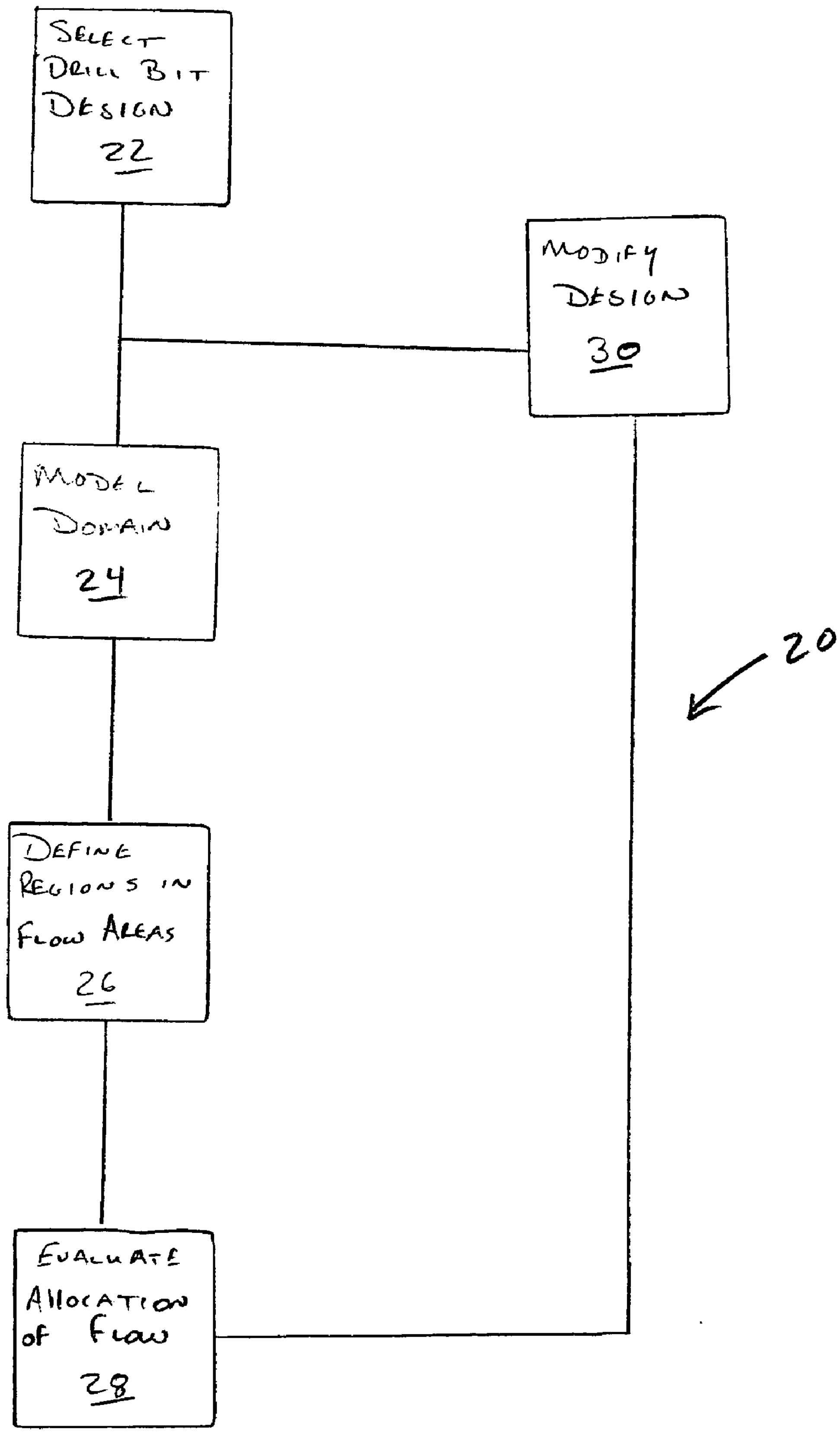

SELECT DRILL BIT DESIGN
22
MODIFY DESIGN
30
MODEL DOMAIN
24
20
DEFINE REGIONS IN FLOW AREAS
26
EVALUATE ALLOCATION OF FLOW
28

Fig 2

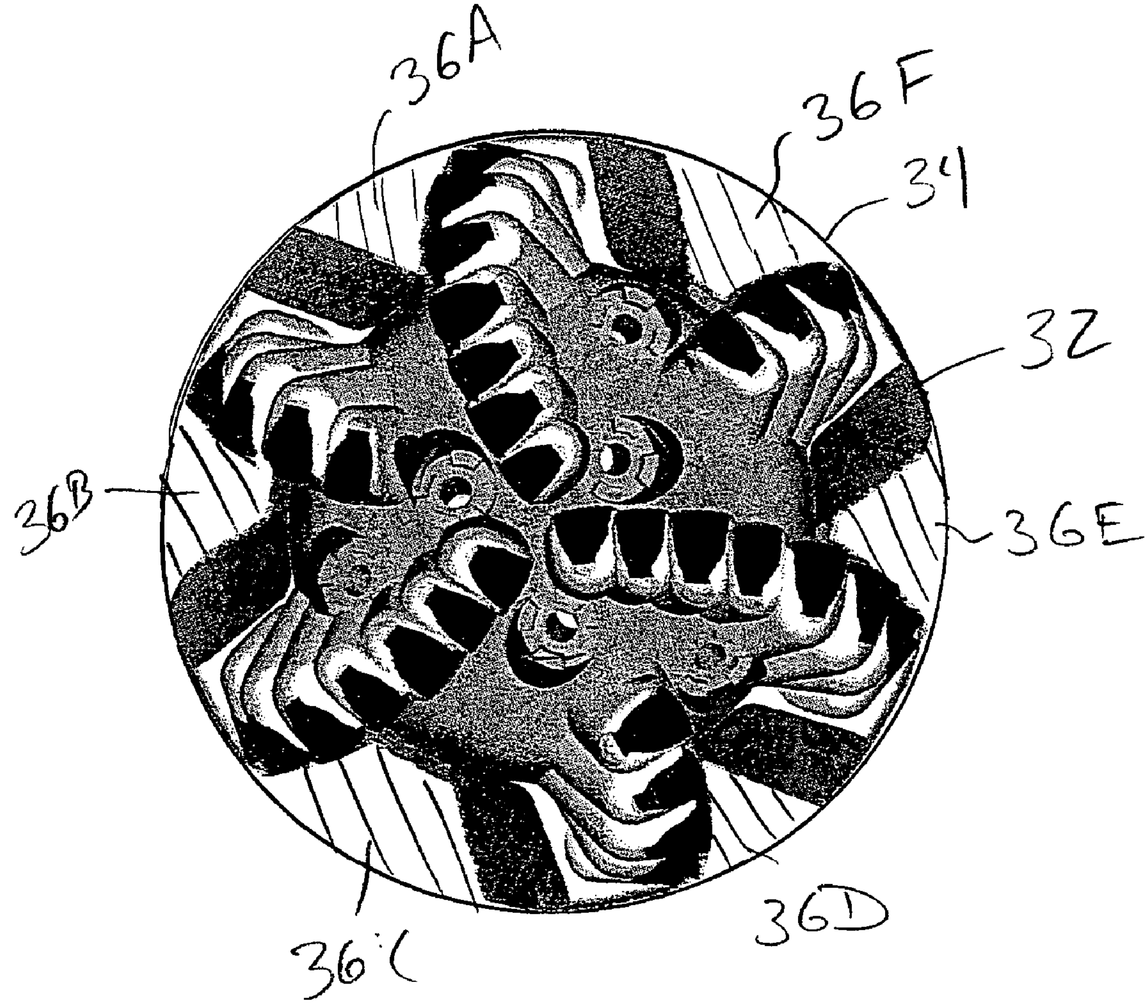


Fig 3

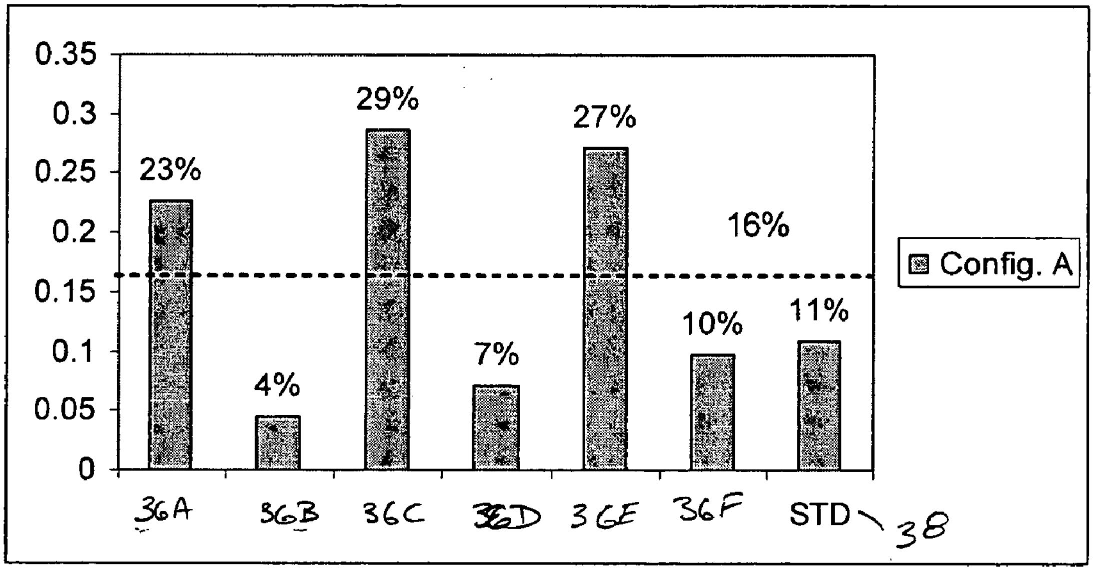

0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
23%
4%
29%
7%
27%
10%
11%
16%
Config. A
36A
36B
36C
36D
36E
36F
STD
38

Fig 4

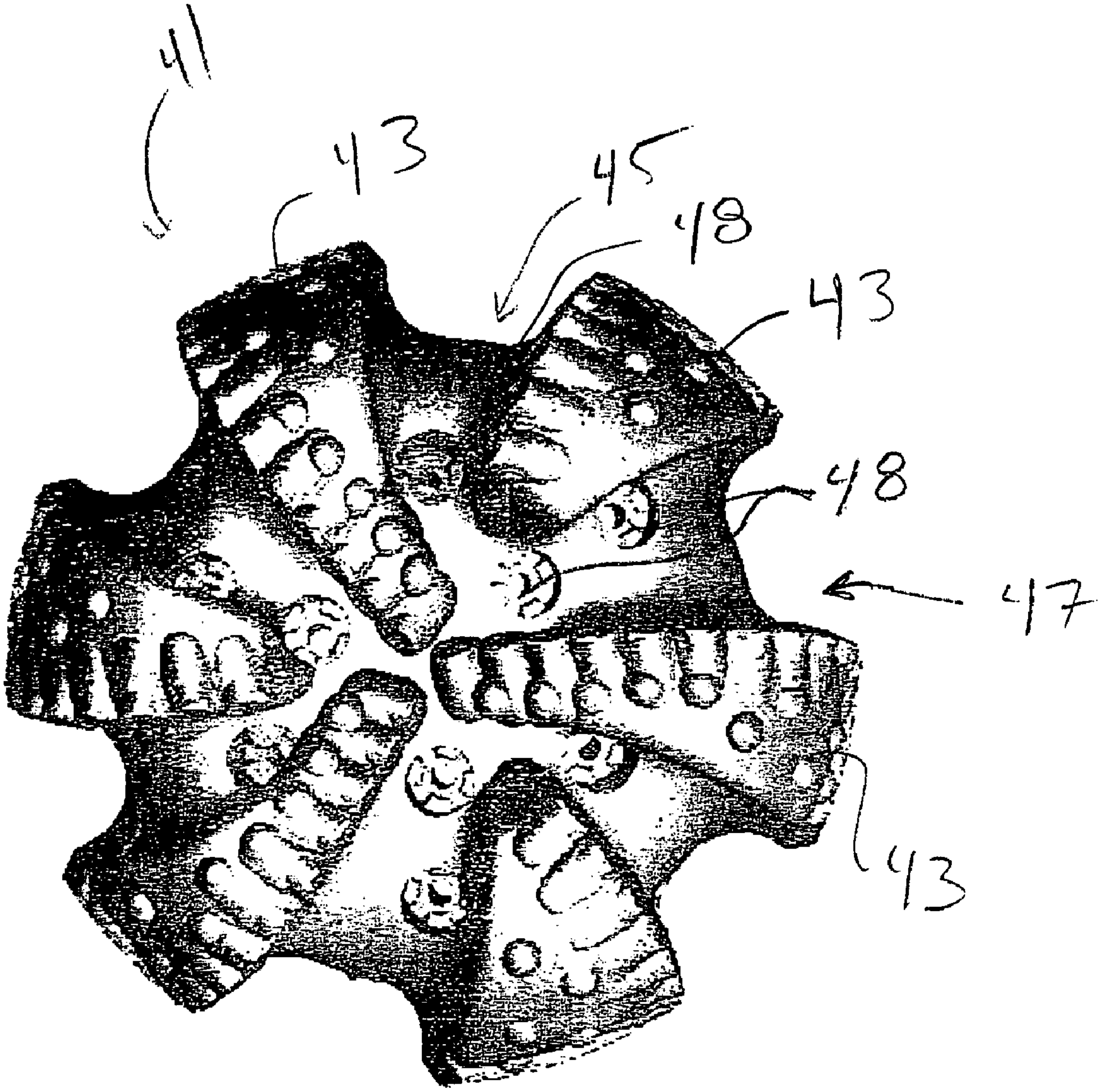


Fig 5

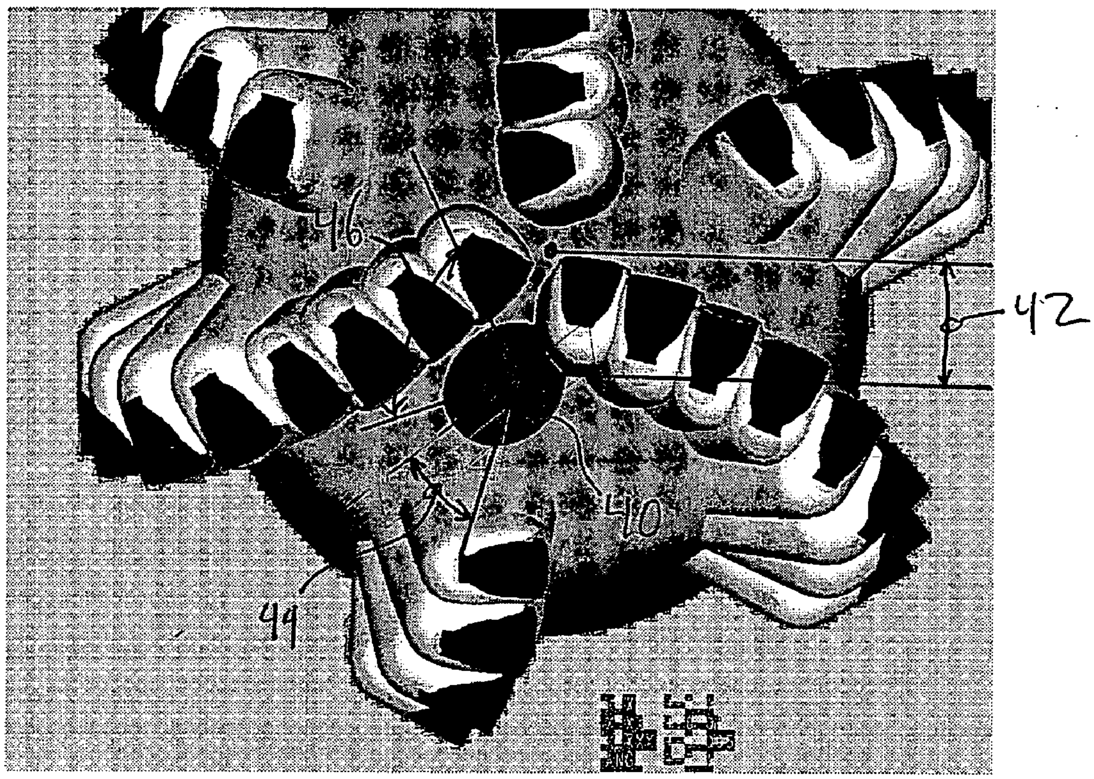


Fig 6

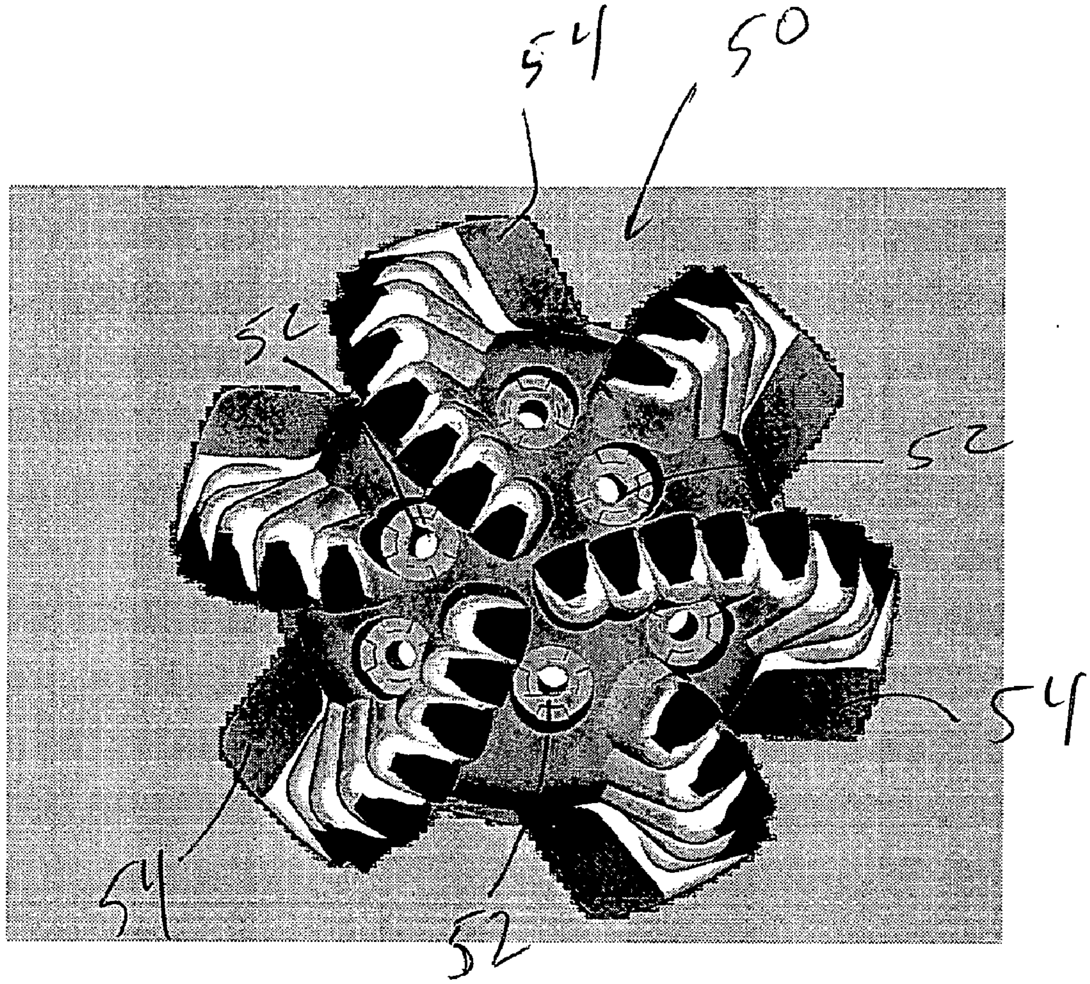


Fig 7

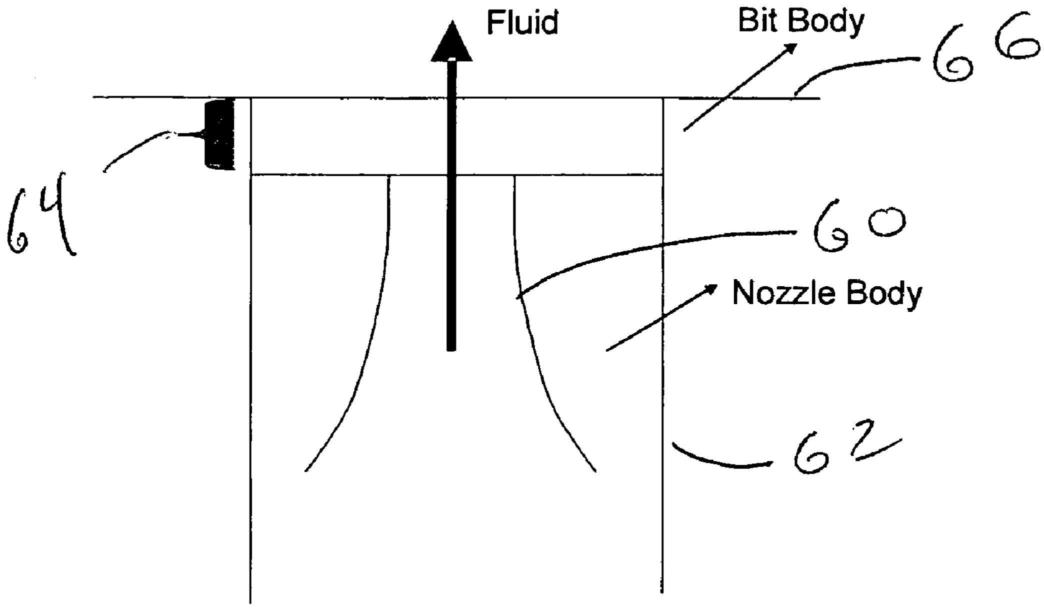

Fluid
Bit Body
66
64
60
Nozzle Body
62

Fig 8

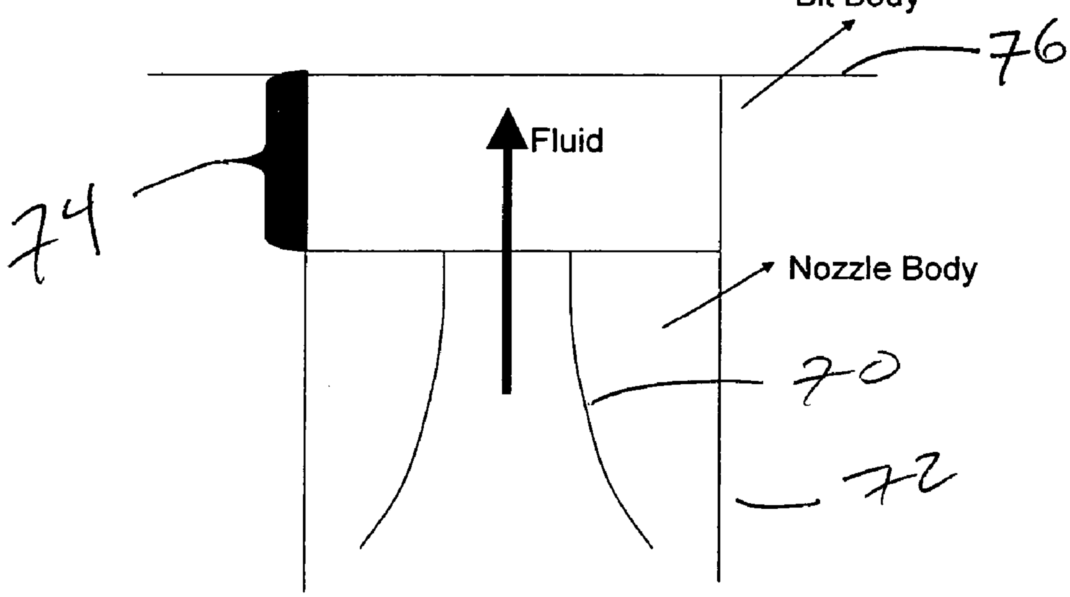

Bit Body
76
Fluid
74
Nozzle Body
70
72

Fig 9

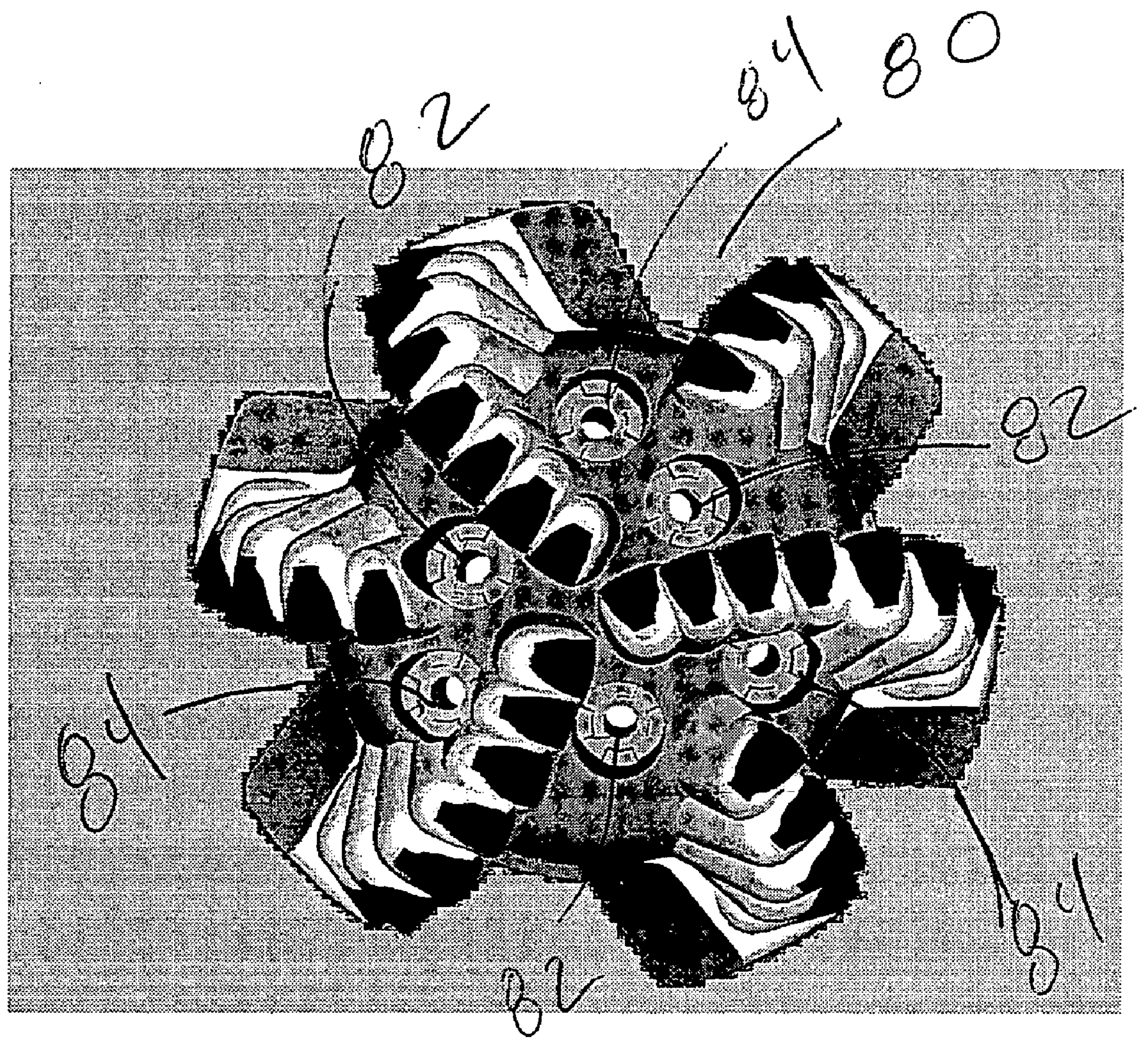


Fig 10

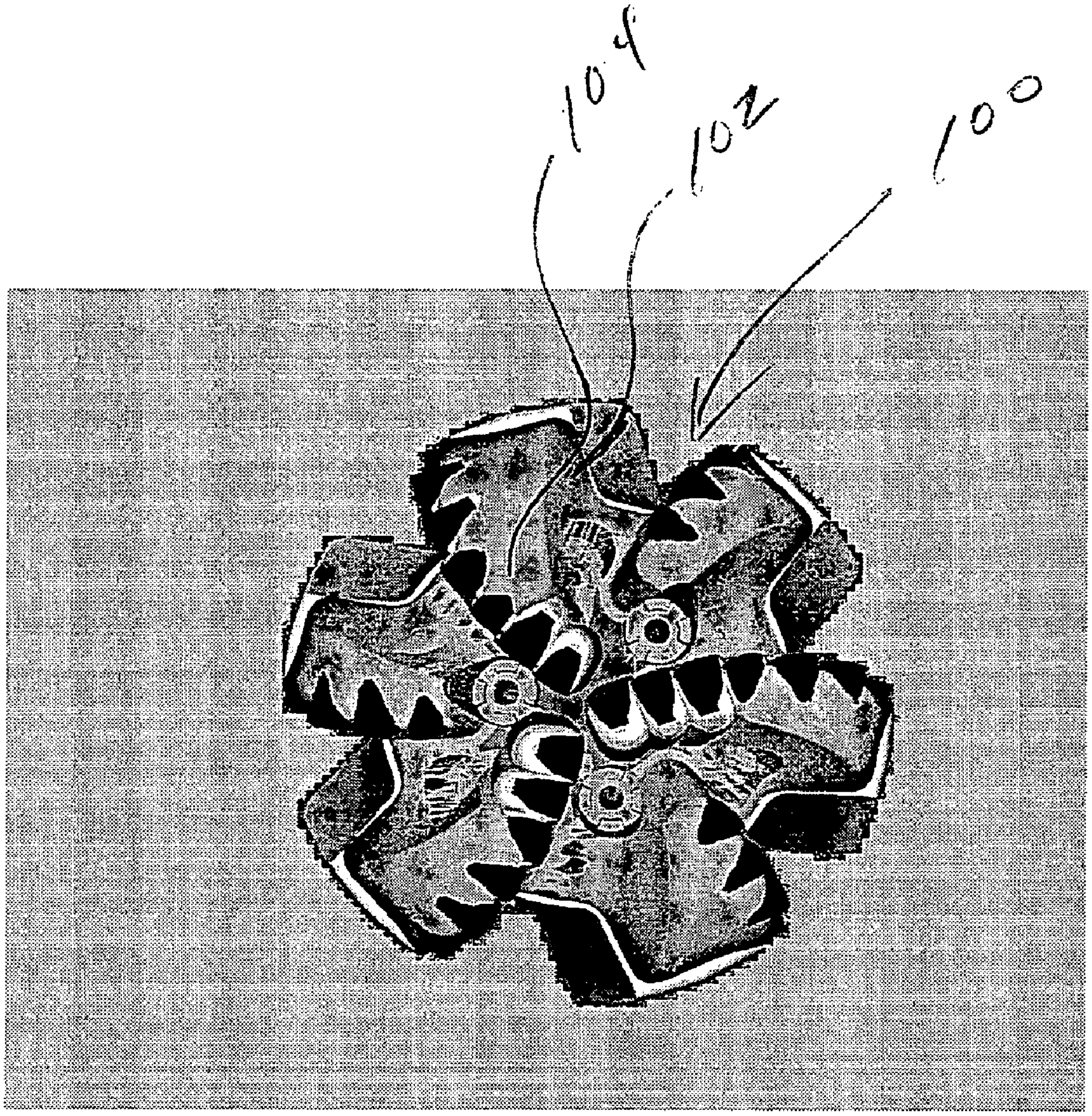


Fig 11

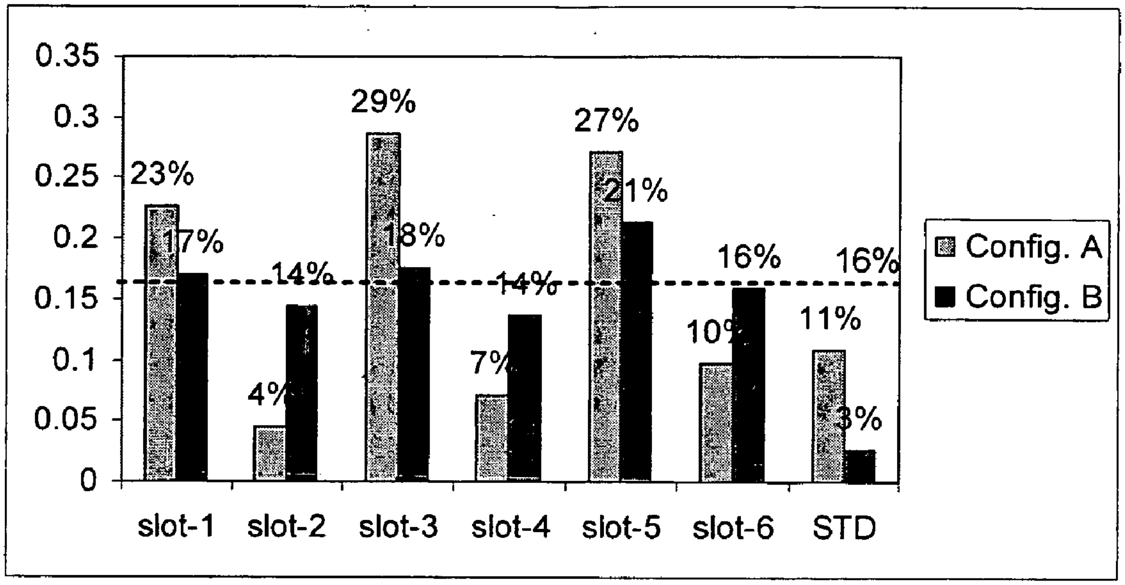

0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
23%
17%
4%
14%
29%
18%
7%
14%
27%
21%
10%
16%
11%
3%
16%
slot-1
slot-2
slot-3
slot-4
slot-5
slot-6
STD
Config. A
Config. B

fig 12

FLOW ALLOCATION IN DRILL BITS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of, and incorporates by reference, provisional application Ser. No. 60/618,060, filed Oct. 12, 2004, and entitled "Flow Allocation in Drill Bits."

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

BACKGROUND

[0003] The present invention relates generally to earth boring drill bits. More particularly, the present invention relates to methods and apparatus used to allocate and control fluid flow through and around earth boring drill bits. Still more particularly, the present invention relates to methods that use hydraulic analysis to determine the fluid flow through and around earth boring drill bits and apparatus that provide for the adjustment or variation of certain drill bit parameters in order to allocate and control the fluid flow.

[0004] In rotary drilling applications, an earth boring drill bit is disposed at the end of a rotating drill string. A fluid is pumped down through the drill string to the bit, where it exits the bit through one or more nozzles or ports. The interaction of the fluid with the drill bit and the surrounding formation is an important aspect of drill bit design and performance. This system of interaction is known as "bit hydraulics." Evaluation of bit hydraulics generally comprises analyzing three primary functions of the hydraulics, namely: cutting structure cleaning/cooling; bottom hole cleaning; and cuttings evacuation.

[0005] Cutting structure cleaning is the ability of the hydraulic fluid to remove formation materials from the bit's cutting structure. Accumulation of formation materials on the cutting structure can reduce or prevent the penetration of the cutting structure into the formation. Cutting structure cooling is the ability of the hydraulic fluid to remove heat, which is caused by contact with formation, from cutting elements in order to prolong cutting element life. Bottom hole cleaning is the ability of the hydraulic fluid to remove cut formation materials from the bottom of the hole. Failure to remove formation materials from the bottom of the hole can result in subsequent passes by cutting structure to re-cut the same materials, thus reducing cutting rate and potentially increasing wear on the cutting surfaces. Cuttings evacuation is the ability of the hydraulic fluid to move cut formation particles away from the area immediately surrounding the drill bit. Failure to circulate formation cuttings up the annulus and away from the drill bit can also lead to reduced penetration rates and premature wear of cutting surfaces.

[0006] The three functions of bit hydraulics should be properly addressed through bit hydraulic design to provide for best overall bit performance. However, because each drilling situation may be significantly or slightly different depending on many factors, careful consideration should be paid to the bit hydraulic system design. The drilling situation depends on factor that include, but are not limited to, the bottom hole assembly, drilling fluid type, rig capability, formation type, drilling rate, and drilling depth.

[0007] Also playing an important role in this bit hydraulics system design is the style or method by which fluid is discharged from the bit. Commonly, a nozzle receptacle receives an erosion resistant, replaceable nozzle through which fluid is discharged. This receptacle oftentimes is an integral feature of the bit made during the manufacturing process and offers means for orientation and retention to the separate nozzle part when installed. Common means of nozzle retention include by screw thread, snap-ring, or nail, however other means do exist.

[0008] Nozzle selection is an important step in designing a bit hydraulics system. Fundamental selection aspects include the nozzle orifice diameter and nozzle design. Nozzle orifice diameter, or nozzle size, directly relates to the nozzle's ability to restrict flow and create desired pressure loss. In addition to diameter, the total-flow area (TFA) of a nozzle can be used as a basis for nozzle size selection and can be determined by calculating the cross sectional area of the nozzle at its exit. In cases of difficult to measure geometry, TFA can be determined experimentally and presented as an equivalent-TFA relative to some known situation. In general, increasing orifice diameter or TFA of a nozzle can result in a higher efficiency nozzle having less fluid restriction and a smaller magnitude pressure loss for a given flowrate.

[0009] Another element for nozzle selection is nozzle design. Some nozzles are designed to discharge fluid streams with very little jet expansion resulting in more concentrated and efficient energy delivery whereas other designs, such as diffusers, encourage diffusion and mixing and still others significantly redirect the discharging fluid stream. The large number of nozzle designs available exists to facilitate adjusting bit performance in the various different drilling applications and situations.

[0010] As an alternative to replaceable nozzles, the discharge location may comprise a nozzle port, which is a fluid passageway formed between the internal portion of the bit and the bit exterior. Ports generally do not allow the end-user flexibility to adjust its configuration. In most instances, the port's configuration is adjusted by modifying the passage geometry and is implemented in manufacturing. Similarly, as with replaceable nozzles, the larger TFA ports are less restrictive and thus produce lower magnitude pressure losses. Also, as with replaceable nozzles, various port designs are available for a large variety of intended drilling applications.

[0011] There are two predominate types of rock bits, namely roller cone rock bits and rotary drag bits. Commonly, drag bits are referred to as polycrystalline diamond cutter (PDC) bits since cutters contain polycrystalline diamond on the cutting surface. Drag bits are often characterized by cutters grouped and placed on several blades. Many drag bit designs include primary blades, secondary blades, and sometimes even tertiary blades, where the primary blades are generally longer and start at locations closer to the bit's rotating axis. The blades project radially outward from the bit body and form flow channels therebetween. Drag bits also include nozzles or fixed ports that serve to inject fluid into these flow passageways. As fluid is injected from the nozzles and flows through the flow channels, the fluid removes cuttings and cleans the cutting structure. The fluid carries the cuttings through the flow channels and upwards into the annulus through the passageways formed by the blades of the drill bit and the surrounding hole, which are commonly known as "junk slots." The movement of fluid through the junk slots is an important factor in the performance of the drill bit.

[0012] Thus, there remains a need to develop methods and apparatus that provide improved bit hydraulic performance by providing for an evaluation the allocation of flow across the bit as well as bit design features that allow for adjusting and controlling the allocation of flow in order to overcome some of the foregoing difficulties while providing more advantageous overall results.

SUMMARY OF THE PREFERRED EMBODIMENTS

[0013] The preferred embodiments include methods for designing drill bits having bit parameters that provide a substantially balanced flow among a plurality of flow paths. A method for designing a drill bit comprises modeling a domain between a drill bit and a surrounding wellbore. A region is defined within each of a plurality of flow paths through which fluid travels through the domain. An allocation of flow among the plurality of flow paths through the domain is determined and the drill bit is modified such that the allocation of flow is substantially uniform among the plurality of flow paths. A drill bit comprises a bit body having a plurality of blades projecting there from, wherein at least one blade has a greater length than at least one other blade. A plurality of nozzles, or ports, are disposed on the bit and a plurality of junk slots are formed between adjacent blades so that the flow of fluid through each of the plurality of junk slots is substantially uniform.

[0014] Thus, the present invention comprises a combination of features and advantages that enable it to overcome various problems of prior devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

[0016] **FIG. 1** is a bottom view of a drag bit;

[0017] **FIG. 2** is a flowchart representing a method for designing a drill bit have a substantially uniform allocation of flow;

[0018] **FIG. 3** illustrates the flow areas through the junk slots of a drag bit;

[0019] **FIG. 4** is a graph representing the allocation of flow through the junk slots of a drag bit;

[0020] **FIG. 5** illustrates one embodiment of a drag bit having multiple nozzles in a single junk slot;

[0021] **FIG. 6** illustrates nozzle parameters for a single nozzle of a drag bit;

[0022] **FIG. 7** illustrates one embodiment of a drag bit having nozzles with adjusted nozzle parameters;

[0023] **FIG. 8** illustrates a nozzle having a shallow seat depth;

[0024] **FIG. 9** illustrates a nozzle having an increased seat depths;

[0025] **FIG. 10** illustrates a drag bit having nozzles with adjusted seat depths;

[0026] **FIG. 11** illustrates a drag bit with increased blade fill; and

[0027] **FIG. 12** is a visual representation of the allocation of flow through the junk slots of two different bit designs.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] In one class of embodiments, the present invention includes methods and apparatus that allow a drill bit to be designed, analyzed, and constructed such that flow is substantially uniform among several flow paths that carry fluid away from the drill bit. **FIG. 1** illustrates a drag bit **10** comprises a bit body **12** having three primary blades **14**, three secondary blades **16**, and six nozzles **18**. Primary blades **14** have a greater length than secondary blades **16** and extend closer to the bit's central axis. Junk slots **19** are formed around the circumference of bit body **12** between blades **14**, **16**. Nozzles **18** are disposed on bit **10** generally between blades **14**, **16**. In operation, drilling fluid flows through nozzles **18**, past blades **14** and **16**, and through junk slots **19** as it moves up the annulus toward the surface. As discussed above, the drilling fluid acts to cool the cutting structures and to remove cuttings from the blades as well as from the bottom of the hole as the hole is being drilled.

[0029] Analysis and experience has shown that the distribution or allocation of fluid through the junk slots is not easily predictable. For instance, in a conventional six-bladed bit having six, symmetrically arranged blades, junk slots, and nozzles, one would think each junk slot would receive an amount of fluid equivalent to the other slots (i.e. 16.7% of the total flow through the annulus). However, it has been learned that the fluid distribution for any junk slot could easily have values of 25%, 10%, or 5% due to the interaction between the fluid, bit geometry, and nozzle configuration.

[0030] Therefore, embodiments of the present invention include methods that allow a drill bit to be designed, analyzed, and constructed such that flow is substantially uniformly allocated among the several flow paths that carry fluid away from the drill bit. Embodiments of the present invention include methods that allow a designer to use computational fluid dynamics (CFD) to evaluate drill bit performance. Once a drill bit design is chosen, that design can then be analyzed using CFD to determine the bit's hydraulic performance, including the allocation of flow among several flow paths. The analysis of the hydraulic performance of the bit can be performed as a set of fluid flow and other conditions that are based on identified drilling parameters or other criteria. CFD analysis tools allow detailed analysis of the fluid flow field through and around the drill bit structure and bottom hole region. CFD analysis can provide data that can be used to generate information as to the fluid velocity, pressure, turbulence, direction, temperature, and other fluid characteristics within the modeled volume.

[0031] To analyze a drill bit using CFD, a model is generally designed in a CAD system or other applicable software which creates a set of bounding surfaces which encapsulate the fluidic area of interest. Typically the bounding surfaces, known as the physical domain, will comprise the drill bit and an area representing the drill string, the bore hole that is being drilled, the hole bottom, and an exiting surface up the bore hole, which can be represented by an annular ring between the borehole and the drill string. Once the bounding surface model is complete, a mesh, which may be constructed of various element types, is created in meshing software. This mesh is called the computational domain, or domain, and is used by the CFD solver to calculate a solution comprising the fluidic properties at each element, or cell, within the domain. Once the solver has completed a solution, fluidic properties can be determined at any location within the confines of the domain. In order to better understand the allocation of flow through the domain, methods of analysis and design processes using regions defined within the domain has been developed as a part of certain embodiments of the current invention.

[0032] The following discussion uses a drag bit as an example but the principles and methods discussed herein are equally applicable to other types of bits, including roller cone bits. For example, in analyzing roller cone bits, the designer may want to have substantially uniform flow in the annular space above the gage, which is the outermost surface of the drill bit. In this case, instead of looking at flow allocation in junk slots, one may examine flow allocations in certain angular intervals around the bit.

[0033] As discussed above, certain drill bit designs utilize fixed ports for discharging fluid into the wellbore. In the case when both fixed ports and replaceable nozzles are used on a bit, the adjustment of fluid discharge sizes, orientations and locations can involve both port and nozzle configurations. When the term nozzle is used herein it is understood that it refers to a replaceable nozzle, a fixed outlet port, and any other location from which fluid is discharged from the drill bit.

[0034] Referring now to **FIG. 2**, one such design process **20** utilizes CFD to simulate the flow within a domain. In this method, the first step comprises selecting a drill bit design **22** that may comprise a hydraulic configuration including one or more bit design parameters. In general, bit design parameters are defined as any aspect of the nozzle or port parameters and/or bit geometry parameters that can be changed so as to influence the behavior of the fluid as it circulates through and around the drill bit. Examples of nozzle or port parameters include, but are not limited to, quantity, design, size, location, angular orientation, seat depth, and arrangement. Examples of bit geometry parameters include, but are not limited to blade height, width, and length, blade shape, bit body geometry, bit interior geometry, and number of blades. Other bit geometry parameters may also include, profile, height, and width of blade and blade-fill, transition between body and blades, shape, height, and width of junk slots and waterway, and side-rake, back-rake, location and orientation of cutters.

[0035] Once the drill bit design is selected, the domain between the drill bit and the surrounding wellbore is modeled **24**. Modeling the domain may further comprise constructing a computerized CAD model of a portion of the drill bit and wellbore, generating a mesh, which is also called the computational domain or domain, to represent the space between the drill bit and the surrounding wellbore, and establishing boundary conditions for the domain. A CFD solver is then utilized to simulate flow through the modeled domain and generate a CFD solution. The CFD solution comprises data representing the flow of fluid through the domain including the associated fluidic properties.

[0036] Once the CFD solution is complete, a plurality of regions is defined **26** within the flow paths of fluid moving away from the bit. As an example, **FIG. 3** illustrates a drag bit **32** disposed in a wellbore **34** where a plurality of regions **36**A-F have been defined within the junk slots of bit **32**. Using the CFD solution, the flow allocation among the plurality of regions can be determined. The flow through each region can be represented by a volumetric flow rate, a mass flow rate, a fluid velocity, or any other fluidic property that provides a representation of fluid flow behavior.

[0037] Once the plurality of regions is defined, the base fluidic properties can be found. For example, in one embodiment, each of the regions co-planar surfaces defined within a junk slot. The fluidic property of interest for each region is the volumetric flow rate passing through the defined surface. Generally, the volumetric flow rate through the region is found by integrating the normal velocity over the area of the surface. Depending on the direction of the velocity vector at each point along the surface, the fluid may be moving upward from the surface or downward from the surface In this case, up and down do not indicate up and down relative to gravity but rather opposing directions relative to the local surface normal direction. In one case, a designer may be interested in the amount of fluid that is moving up and the amount of fluid that is moving down. In another case, the designer may also be interested in the volume of the fluid moving up versus the volume moving down which could also be displayed in the form of a ratio Q_{up}/Q_{down}. The designer may be further interested in looking at ratios relative to the total flow moving through the plane, which may be determined as $Q_{tot}=(abs(Q_{up})+abs(Q_{down}))$. Moreover, the designer may be interested in looking at the net flow rate of fluid through the region defined in the junk slot, which may be determined as $Q_{net}=Q_{up}-Q_{down}$ In other embodiments, the fluidic property of interest may be the upward flowing velocity vectors and/or the downward pointing velocity vectors.

[0038] Once the fluidic property data from the individual regions is collected, it can then be processed to determine the allocation of flow among the junk slots or other flow paths. The allocation of flow can then be presented as a visual representation, such as a graph, plot, contour, or other visual representation that is easy to understand and analyze. Referring back to **FIG. 2**, once the fluidic property and allocation of flow has been determined, it can be evaluated **28** by comparing it to a pre-established design criterion (e.g. a maximum standard deviation) or by comparing it to results from a baseline configuration or other solved hydraulic configurations with similar bit body and cutting structure designs in order to look for beneficial fluidic properties and allocation of flow.

[0039] In certain embodiments, it is desirable to provide a substantially uniform flow among the plurality of flow paths through the domain. As it is used herein, substantially uniform flow is where the standard deviation of the fluidic property among the plurality of flow paths is less than 10%. Preferably, substantially uniform flow is where the standard deviation is less than 5% and more preferably where the standard deviation is less than 3%.

[0040] **FIG. 4** shows results from computational fluid dynamics (CFD) simulation for the flow distribution in the junk slots **36**A-F. Junk slot **36**A, **36**C, and **36**E have much stronger flow rates relative to the other junk slots. The standard deviation **38** of the percentage of flow rates is 11% and indicates a higher than desired non-uniformity of flow through the different junk slots **36**A-F. The high non-uniform flow rates through the junk slots may cause undesirable fluid circulation above the drill bit. The junk slots with lower flow rates (**36**B, D, F) will typically have a larger degree of fluid circulation within the junk slots. This intra-slot circulation may form loops such that cuttings carried away through the high flow rate junk slots from the hole-bottom are circulated back to the hole-bottom through the junk slots with lower flow rates.

[0041] Referring back to **FIG. 2**, based on the evaluation of the flow allocation, the drill bit design can then be modified **30**. Once the drill bit design is modified, the method shown in **FIG. 2** can be run again with a modified domain being modeled between the new drill bit design and the surrounding wellbore. Again, a plurality of regions is defined in the same locations to evaluate the flow allocation. This process is repeated until the evaluation **28** of the series of simulations indicate a preferential interior surface parameter, or set of parameters, for the final design. In this manner, the modified drill bit design can be evaluated to determine if the changes made improved the flow allocation and drill bit performance.

[0042] There are several approaches to improve the uniformity of the flow distribution in the junk slots. These approaches can include, but are not limited to, adjusting one or a combination of bit design parameters comprising nozzle parameters and/or bit geometry parameters. Because the selection and installation of nozzles is often undertaken in the field, in certain embodiments, it may be desired to achieve improved uniformity of flow distribution by modifying bit parameters independent of nozzle size. For example, in certain embodiments, substantially uniform flow may be achieved in a multiple blade drag bit that has one nozzle per blade by configuring the nozzles such that the radial locations, nozzle seat depth, nozzle skew and profile angles are substantially the same and modifying the blade geometry, such as blade length or thickness, including where at least one of the blades does not extend to bit center.

[0043] In other embodiments, a bit design may have a plurality of primary blades and a plurality of secondary blades. The primary blades extend closer to the bit's central axis than the secondary blades. The bit has a set of primary nozzles associated with the primary blades and a set of secondary nozzles associated with the secondary blades. To generate a substantially uniform flow through the junk slots, the primary nozzles may be located further inboard (i.e. closer to the central axis) and have less profile angle and/or less (i.e. shorter) seat depth than the more radially outboard secondary nozzles.

[0044] Certain bits may also have more than two sets of nozzles with nozzles within a set having similar parameters that are different from parameters of nozzles within other sets. Multiple-blade drag bits may also have multiple nozzles per blade or more than one nozzle in a given junk slot. In certain embodiments, more than one nozzle may be positioned in a given junk slot while another junk slot has only a single nozzle. Referring now to **FIG. 5**, drill bit **41** comprises blades **43**, junk slots **45** and **47**, and nozzles **48**. Two nozzles **48** are disposed within junk slot **47** while junk slot **45** only has one nozzle **48**. In certain embodiments, nozzles at the same radius may have substantially the same nozzle parameters such that the inner-most nozzles have similar parameters and outer-most nozzle have similar parameters, where the two sets not being equal.

[0045] Referring now to **FIG. 6**, in one embodiment, the bit design can be modified by adjusting one or more nozzle parameters. One such nozzle parameter is the nozzle orientation, or angular orientation, which in one case may be described as comprising the skew angle **44** and profile angle **46**. As the angular orientation increases, the nozzle is tilted more radially outward from the center of the bit body. In one example, the nozzle has a nozzle axis along the center line of the fluid flow path from the nozzle. The nozzle also has a nozzle plane that is a plane through the nozzle axis and parallel to the bit axis. The skew angle **44** is the angle between the nozzle plane and the plane through the bit axis and the intersecting point of the nozzle axis and the bit body. The profile angle **46** is the angle between the nozzle axis and an axis on the nozzle plane that is collinear to the bit axis. Another nozzle parameter is nozzle location **48**, which is defined as the radial, axial, and angular location of the nozzle relative to the bit's central axis. In certain embodiments, adjusting the nozzle location of one or more of the nozzles so that at least one nozzle has a radial, axial, or angular location that is different than a radial, axial, or angular location of another nozzle may result in a substantially uniform flow. Those skilled in the art will appreciate that the invention is not limited by the example definitions of nozzle orientation and nozzle location provided above.

[0046] An example of a bit having adjusted nozzle parameters is shown in **FIG. 7** where bit **50** utilizes smaller angular orientations for nozzles **52** that are closer to primary blades **54** so as to direct fluid at the portions of the blades that are closer to the bit axis. As a result, the impingement angles formed by the primary jet axis and the hole-bottom profile are close to impingement angles of the secondary jets. Therefore, in certain embodiments, adjusting the angular orientations for one or more of the nozzles so that at least one nozzle has a angular orientation that is different than a angular orientation of another nozzle may result in a substantially uniform flow.

[0047] Another nozzle parameter that can be adjusted is seat depth, or how far the nozzle is recessed into the bit body. Referring now to **FIGS. 8-10**, an increased seat depth for the nozzles further away from the bit axis can also be used to adjust the flow distribution. **FIG. 8** shows a schematic of a nozzle **60** on a bit body **62** with "standard" nozzle seat depth **64** relative to the bit body surface **66**. **FIG. 9** shows a nozzle **70** on a bit body **72** and having an increased seat depth **74** relative to the bit body surface **76**. **FIG. 10** shows a six-blade bit **80** where the primary nozzles **82**, which are closer to the bit axis, have a shallower nozzle seat depth than secondary nozzles **84**. Therefore, in certain embodiments, adjusting the seat depth for one or more of the nozzles so that at least one nozzle has a seat depth that is different than a seat depth of another nozzle may result in a substantially uniform flow.

[0048] In one or more embodiments, smaller exit area nozzles can be used to provide further uniformity to the flow distribution. Smaller exit area nozzles may be desired for use with those junk slots that show a large flow rate when equal sized nozzles are used. In other embodiments, a nozzle having a design that creates a large flow rate through a particular slot could be replaced be a nozzle having the same nozzle exit area, but of somewhat hydraulically inefficient design so as to effectively reduce the flow rate through the junk slot. Conversely, an exhibited low flow rate could be remedied by replacing the nozzle with one having a more hydraulically efficient design to increase the flow. Thus, in certain embodiments, adjusting the size or design of one or more of the nozzles so that at least one nozzle has a size or design that is different than a size or design of another nozzle may result in a substantially uniform flow.

[0049] It has also been found that fluid can flow in and out of a given junk slot by crossing the blade, in particular the upper portion of the blade near the blade top. Thus, in another embodiment, a bit design parameter that can be adjusted is blade geometry, such as the size and shape of the blades. For example, additional supporting material can be added to the back of the blades or the blades can be made thicker. Not only does the additional material support the cutting structure, the material can also prevent or reduce fluid flow across the top of the blades. Hence, fluid flows within each passage and junk slot with less interference from cross-flow. The added blade material may protrude as close as desired to the hole-bottom. One embodiment of a bit having adjusted blade geometry is shown in **FIG. 11**, where bit **100** includes blades **104** having additional material **102** added to the upper portion of the blades. Alternatively, in one or more embodiments, secondary blades may extend closer to the bit axis so as to reduce flow interference between different flow passages and increase the uniformity of flow. In other embodiments, the blade geometries are formed such that fluid flow across the top of the blades is allowed such that the flow distribution in the junk slots is substantially uniform.

[0050] **FIG. 12** shows a comparison of the flow distribution of a new configuration and flow distribution in the original configuration of **FIG. 1** (labeled Configuration A). The embodiment of configuration B has additional blade material and employs smaller angular orientation and smaller nozzle depth for one or more nozzles. Results are obtained from a CFD analysis such as that described in **FIG. 2**. The standard deviation reduced from 11% to 3% for the new configuration. Thus, the new configuration is considered to have a more uniform flow distribution, or a balanced flow distribution. An even distribution of 16.7% in each of the junk slots with zero standard deviation as shown with the dash line.

[0051] Thus, embodiments of the present invention include apparatus and methods that allow a designer to establish a desirable flow allocation by adjusting various bit design parameters. A given drill bit design is analyzed to determine how the flow around the bit is allocated among a plurality of flow paths. Results of the analysis are then evaluated to determine if the flow allocation is within desirable limits. The bit design parameters can then be altered to adjust the flow allocation and the bit design analyzed again. Thus, this method provides multiple design iterations so as to determine the optimum flow allocation for a particular drill bit design and application.

[0052] Under this design methodology, the designer, using computer-aided design software and/or laboratory testing, can perform a thorough evaluation of the bit hydraulics prior to testing in the field, thus helping to prevent expensive downhole problems. This method may include the use of Computational Fluid Dynamics (CFD) software to determine the flow field parameters around a bit and a method of evaluation to determine the fluid flow around a bit and identify manufacturer controlled bit parameters that can be adjusted to control the allocation of the fluid flow.

[0053] In certain applications, the described flow allocation methodologies can be used to create specific situations other than uniform flow, such as biasing the flow allocation toward one region of the bit. For example, a five bladed bit may benefit from having flow allocations of 23%, 18%, 23%, 18%, and 18% instead of the uniform 20%. This non-uniform allocation of flow may be desirable in addressing an area of the bit that has shown a need for additional cooling or cleaning.

[0054] While limited embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teaching of this invention. The embodiments described herein are merely examples and are not limiting by the type and configuration of the drill bit. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied, so long as the apparatus retain the advantages discussed herein.

What is claimed is:

1. A method for designing a drill bit, comprising:

modeling a domain between a drill bit having a first design and a surrounding wellbore;

defining a plurality of regions, wherein one of the plurality of regions is disposed within each of a plurality of flow paths through which fluid travels through the domain;

determining an allocation of flow among the plurality of flow paths through the domain; and

modifying the first design of the drill bit such that the allocation of flow is substantially uniform among the plurality of flow paths.

2. The method of claim 1 wherein the plurality of regions are disposed within junk slots.

3. The method of claim 1 wherein the first design is modified by adjusting a nozzle or port parameter.

4. The method of claim 3 wherein the nozzle or port parameter is an angular orientation, position, size, or seat depth.

5. The method of claim 1 wherein the first design is modified by changing the number of nozzles or ports.

6. The method of claim 1 wherein the first design is modified by adjusting a bit geometry parameter.

7. The method of claim 6 wherein the bit geometry parameter is a blade size, blade shape, or bit body geometry.

8. The method of claim 1 wherein the flow allocation is determined based on a fluidic property of fluid moving through the plurality of regions.

9. The method of claim 8 wherein the fluidic property is a volumetric flow rate, mass flow rate, or net flow rate.

10. The method of claim 1 further comprising:

modeling a modified domain between a drill bit having a modified design and the surrounding wellbore;

defining a plurality of regions within the modified domain, wherein each region is disposed within each of a plurality of flow paths through which fluid travels through the modified domain;

determining an allocation of flow among the plurality of flow paths through which fluid travels through the modified domain; and

selecting a bit design based on a comparison of the allocation of flow among the flow paths in the modified domain and the allocation of flow among the flow paths in the unmodified domain.

11. The method of claim 1 further comprising generating a visual representation of the allocation of flow among the flow paths.

12. A drill bit comprising:

a bit body having a plurality of blades projecting there from, wherein at least one blade has a greater length than at least one other blade;

a plurality of nozzles or ports disposed on said body; and

a plurality of junk slots formed between adjacent blades, wherein said junk slots provide a passageway for the flow of the fluid from said plurality of nozzles or ports, wherein bit design parameters are such that the flow of fluid through each of the plurality of junk slots is substantially uniform.

13. The drill bit of claim 12 wherein the bit design parameters comprise a nozzle or port parameter or a bit geometry parameter.

14. The drill bit of claim 12 wherein at least one of said plurality of nozzles or ports has nozzle or port parameter that is different than a nozzle or port parameter of another of said plurality of nozzles or ports.

15. The drill bit of claim 12 wherein the nozzle or port parameter comprises at least one of, quantity, design, size, radial location, axial location, angular orientation, seat depth, and arrangement.

16. The drill bit of claim 12 wherein at least one of said junk slots has a greater number of said plurality of nozzles or ports positioned there within than are positioned within another of said plurality of junk slots.

17. The drill bit of claim 12 wherein at least one of said plurality of blades has more material at an upper portion of the blade, extends farther toward a central bit axis, or has a greater thickness than another of said plurality of blades.

18. The drill bit of claim 12 wherein said plurality of nozzles or ports comprises a number of nozzles or ports equal to the number of said plurality of blades.

19. A drill bit of claim 12 further comprising:

a central bit axis through the bit body; and wherein the plurality of blades extending from said bit body, wherein said plurality of blades comprises at least one primary blade and at least one secondary blade, wherein at least one of the primary blades extends closer to the central bit axis than at least one of the secondary blade.

20. The drill bit of claim 19 wherein said plurality of nozzles or ports comprises at least one primary nozzle or port and at least one secondary nozzle or port.

21. The drill bit of claim 19 wherein the at least one primary nozzle or port is located closer to the bit central axis than the at least one secondary nozzle or port.

22. The drill bit of claim 19 wherein the at least one primary nozzle or port has a smaller angular orientation than the at least one secondary nozzle or port.

23. The drill bit of claim 19 wherein the at least one primary nozzle or port has a shorter seat depth than the at least one secondary nozzle or port.

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