DIMATEC INC.

Operating Parameters: Bit Hydraulics

Determination of in-hole fluid circulation parameters

Typically, the circulating fluid is pumped from the surface through the drill string, between the inner and outer tubes of the core barrel assembly, across the bit face and then returns to the surface through the annular gap between the drill string and the drill hole wall. The basic rule is that the ascending velocity of the circulating fluid should be greater than the precipitation velocity of the largest cuttings in the fluid. As such, the larger the cuttings, the more fluid is needed.

While bit hydraulics are controlled to some extent by regulating the drill's circulating pump and circulating fluid viscosity, the actual amount of circulating fluid to apply is largely determined by the bit face waterway configuration as well as the annular gap between the outside diameter of the drill string and the drill hole wall. As conditions vary considerably from one drilling operation to another, it is difficult to define absolute parameters for in-hole fluid circulation. Some on-site experimentation may be required.

Annular velocity is defined as the rate at which the circulating fluid and cuttings from the bit are returned to the surface through the annular gap between the drill hole wall and the drill string. Excessive annular velocity may cause hydraulic erosion of the drill hole wall in soft formations while insufficient annular velocity will cause cuttings to remain suspended in the circulating fluid. This condition will result in stuck drill rods, equipment wear, low penetration rates and hole cave-ins. As an alternative to running with higher annular velocities, the drill operator may increase the viscosity of the circulating fluid for effective hole cleaning.

The normal recommendations for annular velocity are:

Maximum: 90 metres/minute (or 290 feet/minute) **Minimum: 60 metres/minute (or 200 feet/minute)**

The amount of fluid velocity and fluid volume to be applied are determined by the primary bit hydraulics functions: namely, the cooling of the bit and the transportation of the cuttings.

Calculation of circulation pump rate (Q)

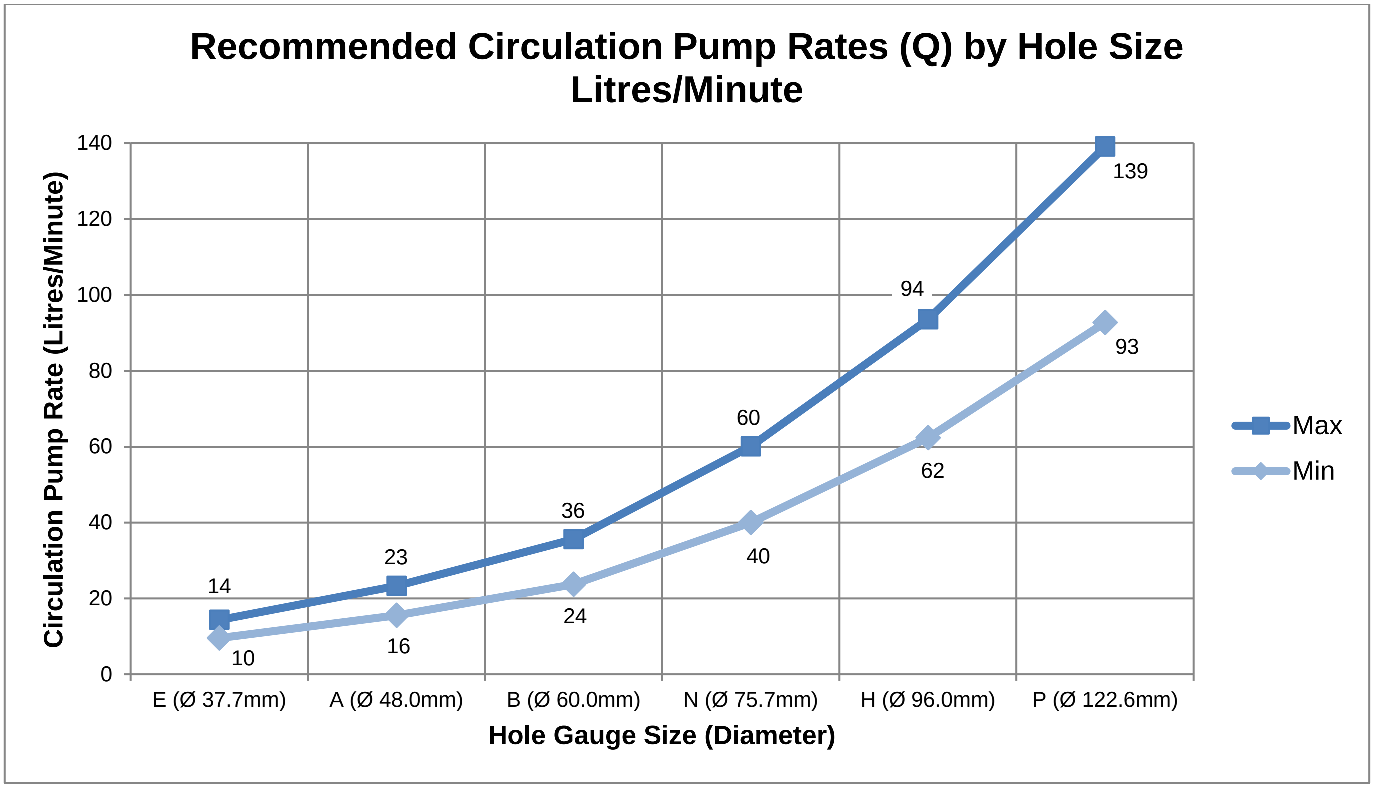
Use the following formula to calculate the maximum and minimum circulation pump rate (Q):

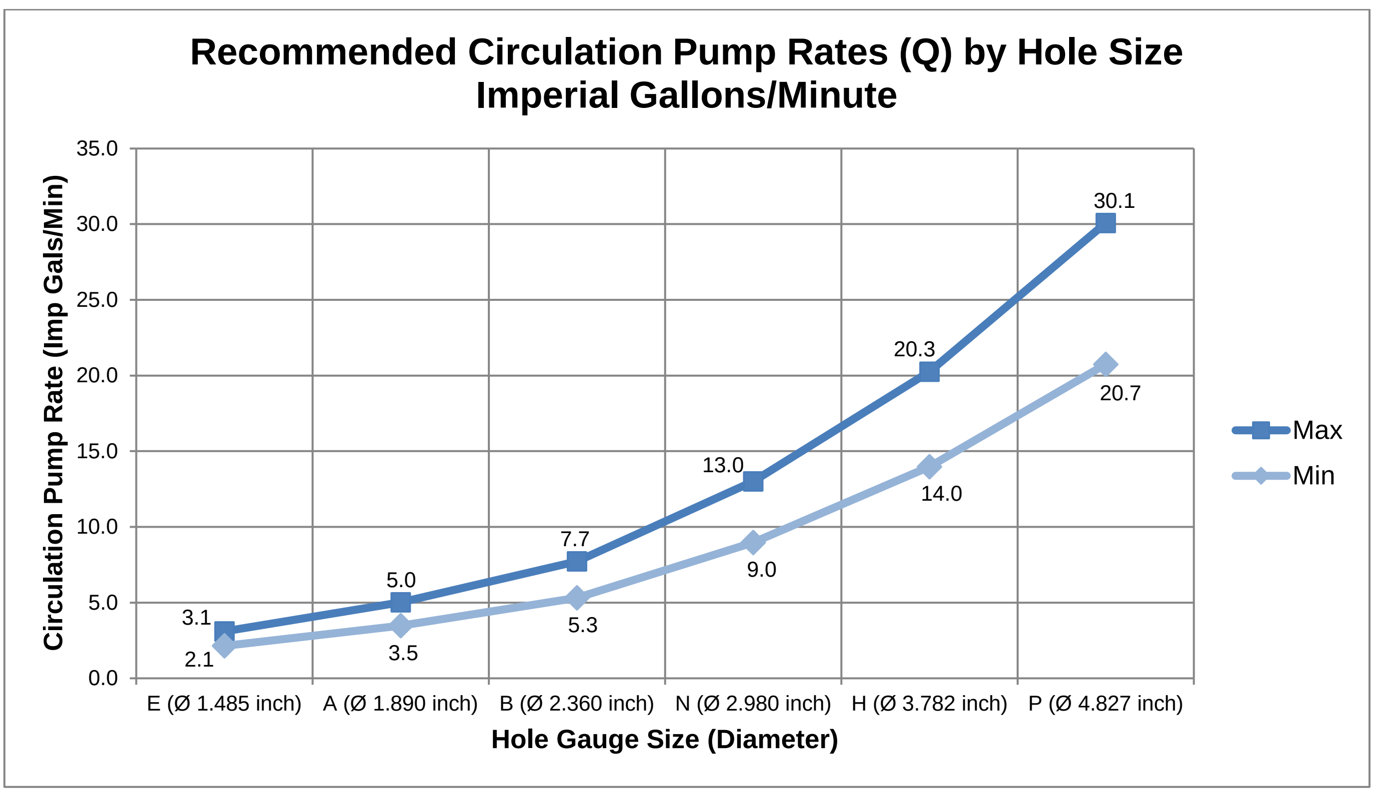
$$Q = V_a \left[\frac{0.785(d^2 - s^2)h}{c} \right]$$

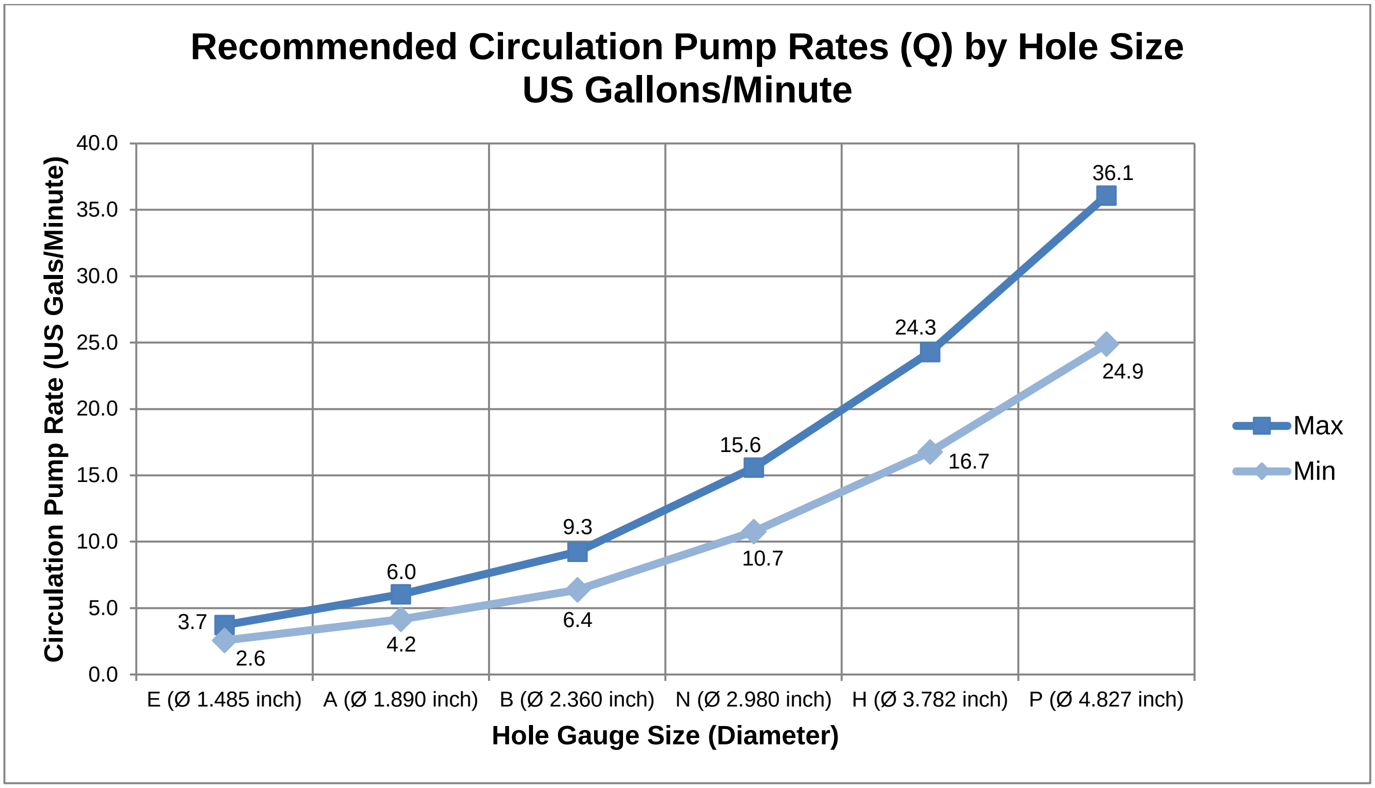
Depending on the system of measurement in use, the formula variables have been defined in the following table:

Variable	Variable Description	Units and Constants		
Q	Pump Rate	US gallons/min	Imperial gal/min	litres/min
V_a	Annular Velocity	feet/min	feet/min	metres/min
h	Unit Height of Annulus	12 inches/foot	12 inches/foot	1000 mm/metre
d	Drill Hole Diameter	inches	inches	mm
s	Drill String Diameter	inches	inches	mm
c	Volume Conversion	231 inch^3/US gallon	277 inch^3/Imp gallon	1×10^6 mm^3/litre

Based on the equation given above along with the maximum and minimum recommended annular velocities, the maximum and minimum recommended circulation pump rates (Q) for the most common drill hole diameter and drill string diameter combinations are given in the following three graphs:







"Q" values approaching the MAXIMUM limit should be used in cases where any of the following are applicable:

- The cuttings that are generated by the bit are relatively large such as those generated by TSP-set or Pax-set core bits.
- The hardness of the formation causes considerable friction on the bit face resulting in high heat generation.
- The formation is relatively consolidated with little or no fluid return loss.

"Q" values approaching the MINIMUM limit should be used in cases where any of the following are applicable:

- The cuttings that are generated by the bit are relatively fine.
- The formation being drilled is susceptible to hydraulic erosion.
- When drilling in very hard, fine-grained formations, it may be desirable to operate diamond impregnated bits at circulation rates approaching (but not below) the minimum recommended pump rate. This will promote some controlled abrasion of the matrix in order to maintain a satisfactory rate of penetration.
- Where the bit in use has a waterway configuration with a small number of narrow fluid passages, the use of a circulation rate that approaches the minimum recommendation will reduce the fluid pressure at the bit face and will in turn reduce the effect of hydraulic lift that tends to counteract the applied bit load.

The flow of circulation fluid must never be completely shut-off to a bit rotating under load.

Special considerations for diamond impregnated bits

1. Bit sharpening: The practice of running a diamond impregnated bit with an excessively low (lower than the minimum recommended) rate of fluid circulation in order to promote matrix stripping (to keep the bit sharp) should be avoided. As an alternative to this technique, temporarily lowering the rotational speed towards the minimum recommended value for a particular bit size will often allow the bit to sharpen itself. The circulation fluid rate should only be lowered if a bit will not sharpen on its own and must be restored to its original setting immediately after the bit has sharpened itself.

2. Drilling in hard, non-abrasive formations: Higher bit loads (weight-on-bit) should only be applied if:
   (a) Circulating fluid rates towards the recommended MAXIMUM are in use or
   (b) A suitable bit lubricant has been added to the circulating fluid solution.

Bit face fluid dynamics

The waterway configuration on the face of a bit has a considerable effect on its performance. By using the same in-hole fluid circulation rate, the **Regular** (Style 'W'), **T-Turbo** (Style 'TT'), **Trapezoidal Extra Wide** (Style 'TXW') and **VORTEX** (Style 'VX') waterway configurations all produce a higher fluid pressure at the bit face than the **Extra Extra Wide** (Style 'XXW'), **Free-Flow** (Style 'FF'), **Face Discharge** (Style 'FD') and **Slot Face Discharge** (Style 'SFD') waterway configurations. The difference in the amount of fluid pressure that is developed at the bit face is related to the total flow area (TFA) of the waterway configuration.

Higher fluid pressures through the fluid passages through which the circulating fluid is introduced to the bit crown, may be desirable when trying to create a jetting action across the bit face to move fine cuttings. Lower fluid pressures through the input ports may be desirable where the formation being drilled is susceptible to hydraulic erosion, where the existence of a hydraulic lift condition is an issue or where fluid turbulence at the bit face hampers performance.

The effect of waterway configuration on input fluid pressure to the bit face for some common diamond impregnated core bits is illustrated in the following table:

Bit Size	Waterway Configuration	TFA *(inch^2)*	Circulation Pump Rate (Q) *(Imperial Gallons / Minute)*		Fluid Pressure Developed *(lbs / inch^2)*	
			Minimum	Maximum	At Q Minimum	At Q Maximum
AWL or AWLTK	6W	0.045	3.5	5.0	6.07	12.39
	5TXW	0.056	3.5	5.0	3.86	7.89
	5XXW	0.075	3.5	5.0	2.19	4.46
AWL	5FD	0.139	3.5	5.0	0.64	1.30
BWL or BWLTK	7TW+7TT (T-Turbo)	0.053	5.3	7.7	10.23	21.59
	8W	0.060	5.3	7.7	7.83	16.53
	6TXW	0.068	5.3	7.7	6.15	12.99
	6XXW	0.090	5.3	7.7	3.48	7.35
BWL	5VX	0.075	5.3	7.7	5.01	10.58
	6FD	0.167	5.3	7.7	1.02	2.15
	6XXWFF	0.236	5.3	7.7	0.51	1.07
NWL or NWL2	6VX	0.090	9.0	13.0	10.04	20.94
	9TW+9TT (T-Turbo)	0.068	9.0	13.0	17.84	37.23
	10W	0.075	9.0	13.0	14.45	30.15
	8TXW	0.090	9.0	13.0	9.98	20.83
	8XXW	0.120	9.0	13.0	5.65	11.78
	8FD	0.222	9.0	13.0	1.65	3.44
NWL	4SFD	0.377	9.0	13.0	0.57	1.19
	8XXWFF	0.504	9.0	13.0	0.32	0.67
NWL2	8XXWFF	0.384	9.0	13.0	0.55	1.15
HWL or HWL3	7VX	0.105	14.0	20.3	17.84	37.51
	11TW+11TT (T-Turbo)	0.083	14.0	20.3	28.90	60.76
	12W	0.090	14.0	20.3	24.28	51.06
	10TXW	0.113	14.0	20.3	15.46	32.50

Bit Size	Waterway Configuration	TFA *(inch²)*	Circulation Pump Rate (Q) *(Imperial Gallons / Minute)*		Fluid Pressure Developed *(lbs / inch²)*	
			Minimum	Maximum	At Q Minimum	At Q Maximum
HWL or HWL3 (Cont'd)	10XXW	0.150	14.0	20.3	8.74	18.38
	10FD	0.278	14.0	20.3	2.55	5.37
	5SFD	0.471	14.0	20.3	0.89	1.92
HWL	10XXWFF	0.703	14.0	20.3	0.40	0.84
HWL3	10XXWFF	0.818	14.0	20.3	0.29	0.64
PWL	13TW+13TT (T-Turbo)	0.111	20.7	30.1	35.22	74.47
	16W	0.136	20.7	30.1	23.25	49.16
	14TXW	0.179	20.7	30.1	13.43	28.39
	12XXW	0.204	20.7	30.1	10.33	21.85
	12FD	0.333	20.7	30.1	3.88	8.19
	6SFD	0.566	20.7	30.1	1.34	2.84
	12XXWFF	1.074	20.7	30.1	0.37	0.79

Specific gravity is a dimensionless quantity that indicates how many times a certain volume of a material is heavier than an equal volume of water. Specific gravity values associated with bit hydraulics pertain to the mixture of water and polymers or drill mud that are used as circulating fluid. Pure water at 62°F (17°C) has a specific gravity of 1.00 and a density of 62.4 pounds/foot^3. Typically, water and drill mud mixtures will have a specific gravity in the range of 1.00 to 1.30 resulting in density values of 62.4 pounds/foot^3 to 81.1 pounds/foot^3.

All of the values for "Fluid Pressure Developed" given in the table above assume that the circulating fluid has a specific gravity of 1.00. The use of circulating fluids with a specific gravity greater than 1.00 will result in higher fluid pressures at the bit face.

In some cases, the density of a drill mud mixture may be given as mass per fluid volume. For example, where a circulating fluid is said to have a density of "10.2 pounds/US gallon", the specific gravity of the mixture (γ) is determined by first converting the given density to pounds/foot^3 using the following formula:

$$\rho = \rho_0 \left(7.48 \frac{US\ gal}{foot^3}\right)$$

Where:
$\boldsymbol{\rho_0}$ = The density of the circulating fluid expressed in pounds/US gallon.

$\boldsymbol{\rho}$ = The density of the circulating fluid expressed in pounds/foot^3.

In the case of this example, the conversion of units from "pounds/US gallon" to "pounds/foot^3" (ρ) is given by the equation:

$$\rho = \left(10.2 \frac{pounds}{US\ gal}\right)\left(7.48 \frac{US\ gal}{foot^3}\right) = 76.3 \frac{pounds}{foot^3}$$

Therefore, the specific gravity (γ) is a ratio of the circulation fluid's density and the density of pure water:

$$\gamma = \frac{\rho}{62.4\ pounds/foot^3}$$

Where:
$\boldsymbol{\rho}$ = The density of the circulating fluid expressed in pounds/foot^3.

In the case of this example, the specific gravity is given by the equation:

$$\gamma = \frac{76.3\ pounds/foot^3}{62.4\ pounds/foot^3} = 1.22$$

Calculation of fluid pressure developed at the face of the bit (P)

Total Flow Area (TFA) is defined as the combined cross-sectional area of all of the fluid input ports. That is, either the sum of the areas of the internal fluid passage canals or the sum of the areas of the face discharge holes or slots moulded into the bit crown.

The actual fluid pressure (P) developed at the face of any bit may be calculated by using the following formula:

$$P = \frac{\left(\frac{Q}{A}\right)^2 \gamma\rho}{2g}$$

Where:
$\boldsymbol{Q}$ = The circulation pump rate given in "inch^3/sec"
$\boldsymbol{A}$ = The TFA for the bit given in "inch^2"
$\boldsymbol{\gamma}$ = The specific gravity of the circulating fluid
$\boldsymbol{\rho}$ = The density of water: a constant of 0.0361 pounds/inch^3
$\boldsymbol{g}$ = The acceleration due to gravity: a constant of 384 inches/sec^2

Conversion factors

Length
1 mm = 0.039 inch
1 inch = 25.4 mm

Force
1 N = 0.225 lbf
1 kN = 225 lbf
1 lbf = 4.45 N

Mass
1 kg = 2.205 lb
1 lb = 0.454 kg

Pressure
1 MPa = 1 N/mm^2
1 MPa = 145 lb/inch^2
1 Bar = 100 kPa = 14.5 lb/inch^2
1 lb/inch^2 = 0.0069 MPa
1 lb/inch^2 = 6.9 kPa

Volume
1 litre = 0.264 gal (US)
1 litre = 0.220 gal (Imperial)
1 gal (US) = 3.785 litres
1 gal (Imperial) = 4.546 litres

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