CHAPTER THREE

Mud Pumps

Contents

3.1 Introduction 61
3.2 Mud Flow Rate Requirements 61
  3.2.1 Extreme Mud Properties 62
  3.2.2 Extreme Annular Geometry 62
  3.2.3 The Minimum Required Flow Rate 62
3.3 Pressure Requirements 66
  3.3.1 Extreme Borehole Configurations 66
  3.3.2 Extreme Borehole Conditions 66
  3.3.3 Circulating Pressure 67
  3.3.4 The Minimum Required Pressure 68
3.4 Horsepower Requirements 72
3.5 Capacities of Mud Pumps 74
  3.5.1 Triplex Pumps 76
  3.5.2 Duplex Pumps 76
Summary 78

3.1 INTRODUCTION

Mud pumps are the most important equipment for providing bit hydraulics required for achieving hole cleaning and a high rate of penetration. They should be selected on the basis of flow rates and circulating pressures required at different stages of hole making. Pump power should also be checked. This chapter provides drilling engineers with guidelines for mud pump selection.

3.2 MUD FLOW RATE REQUIREMENTS

The selected mud pump should be capable of providing mud flow rates that are high enough to transport drill cuttings to the surface at all stages of drilling. Since the efficiency of cuttings transport depends on mud properties and mud flow velocity and these parameters change with hole depth, extreme mud properties and extreme annular geometry should be considered.
3.2.1 Extreme Mud Properties

Mud properties that influence the type of pump include mud weight (density) and rheological properties. For Newtonian fluids, viscosity is the only parameter describing fluid rheological characteristics. Plastic viscosity and yield point are the two parameters used to describe the rheological characteristics of Bingham plastic fluids. The consistency and the flow behavior indexes are the two parameters that are utilized to characterize Power Law fluids, also called pseudoplastic fluids in other industries. The consistency index, the flow behavior index, and yield strength are the three parameters that are employed to characterize Herschel-Bulkley fluids. All of these fluid properties can be measured using state-of-the-art instruments used in the oil and gas industry.

In hole cleaning, the properties of the mud affect the settling velocity of drill cuttings in the annulus. To ensure that drilling operations are done safely, the expected ranges of mud properties should be found from mud programs and listed against the hole depths with different borehole geometries. The extreme values in the ranges of properties will be used for estimating the cuttings settling velocity and thus the minimum required mud flow rate from the mud pump.

3.2.2 Extreme Annular Geometry

The minimum required mud flow rate from the mud pump is equal to the minimum required mud velocity times the maximum possible cross-sectional area of annular space during drilling. Therefore, the information of borehole geometry should be known for selecting mud pumps to drill the wells. Figure 3.1 shows a typical borehole geometry diagram. Drill pipe sizes and the extreme mud properties should be marked in the diagram at each level of open hole sizes.

3.2.3 The Minimum Required Flow Rate

The minimum required mud flow rate demanded by the borehole geometry from the mud pump is estimated based on the minimum required mud velocity, which should be higher than the drill cuttings slip velocity. The criterion for the minimum required mud velocity was described in Chapter 2. For mud pump selection, we consider the minimum mud flow rate required for drilling the hole sections of extreme geometries.
Illustrative Example 3.1

For the borehole geometry and extreme mud properties given in Figure 3.2, determine the minimum required mud flow rate from the mud pump. Assume that the parameter values in Table 3.1 are realistic.

Solution

The solution was obtained using the computer spreadsheet Minimum Flow Rates.xls that is attached to this book. To calculate the minimum flow rate using Table 3.2, (1) select a unit system, (2) update the data in the Input Data column, and (3) click on the Solution button and obtain the result. The result is summarized in Table 3.3. The last column of the table indicates that a mud pump should be selected to be able to provide a minimum mud flow rate of 990 gpm (3.75 m³/min).

(Continued)
### Illustrative Example 3.1 (Continued)

<table>
<thead>
<tr>
<th>Hole Size</th>
<th>Drill Pipe OD</th>
<th>Casing Depth</th>
<th>Casing Size</th>
<th>Mud Weight</th>
<th>Mud Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>24&quot; (610 mm)</td>
<td>65/8&quot; (168 mm)</td>
<td>120' (37 m)</td>
<td>20&quot;, 94 Ib/ft (508 mm, 140 kg/m)</td>
<td>9.2 ppg (1.10 SG)</td>
<td>20 cp (0.020 Pa-s)</td>
</tr>
<tr>
<td>171/2&quot; (445 mm)</td>
<td>65/8&quot; (168 mm)</td>
<td>1400' (427 m)</td>
<td>133/8&quot;, 48 lb/ft (339.7 mm, 71.4 kg/m)</td>
<td>9.6 ppg (1.15 SG)</td>
<td>15 cp (0.015 Pa-s)</td>
</tr>
<tr>
<td>121/4&quot; (318 mm)</td>
<td>5&quot; (127 mm)</td>
<td>7000' (2134 m)</td>
<td>85/8&quot;, 32 lb/ft (219.1 mm, 47.6 kg/m)</td>
<td>10.4 ppg (1.25 SG)</td>
<td>10 cp (0.01 Pa-s)</td>
</tr>
<tr>
<td>77/8&quot; (200 mm)</td>
<td>5&quot; (127 mm)</td>
<td>10000' (3048 m)</td>
<td>77/8&quot; (200 mm)</td>
<td>11 ppg (1.38 SG)</td>
<td>5 cp (0.005 Pa-s)</td>
</tr>
</tbody>
</table>

**Figure 3.2** Example of borehole geometry with extreme mud properties.
Table 3.1 Rock Properties and Drilling Parameters at Different Hole Depths

<table>
<thead>
<tr>
<th>Depth</th>
<th>Cuttings Density</th>
<th>Cuttings Sphericity</th>
<th>Rate of Penetration</th>
<th>Rotary Speed</th>
<th>Cuttings Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft</td>
<td>m</td>
<td>lb/ft³</td>
<td>g/cc</td>
<td>ball = 1</td>
</tr>
<tr>
<td>120</td>
<td>37</td>
<td>162</td>
<td>2.60</td>
<td>0.85</td>
<td>90</td>
</tr>
<tr>
<td>140</td>
<td>427</td>
<td>165</td>
<td>2.65</td>
<td>0.8</td>
<td>70</td>
</tr>
<tr>
<td>7,000</td>
<td>2,134</td>
<td>168</td>
<td>2.70</td>
<td>0.75</td>
<td>50</td>
</tr>
<tr>
<td>10,000</td>
<td>3,048</td>
<td>172</td>
<td>2.75</td>
<td>0.7</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 3.2 Computer Spreadsheet Minimum Flow Rates.xls

<table>
<thead>
<tr>
<th>Input Data</th>
<th>U.S. Units</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuttings specific gravity</td>
<td>2.6</td>
<td>water = 1</td>
</tr>
<tr>
<td>Particle sphericity</td>
<td>0.85</td>
<td>ball = 1</td>
</tr>
<tr>
<td>Drilling fluid viscosity</td>
<td>20 cp</td>
<td>Pa-s</td>
</tr>
<tr>
<td>Drilling fluid density</td>
<td>9.2 ppg</td>
<td>g/cc</td>
</tr>
<tr>
<td>Annulus OD</td>
<td>24 in</td>
<td>mm</td>
</tr>
<tr>
<td>Annulus ID</td>
<td>6.625 in</td>
<td>mm</td>
</tr>
<tr>
<td>Rate of penetration</td>
<td>90 ft/hr</td>
<td>m/hr</td>
</tr>
<tr>
<td>Rotary speed</td>
<td>70 rpm</td>
<td>rpm</td>
</tr>
<tr>
<td>Cuttings concentration</td>
<td>15%</td>
<td>%</td>
</tr>
</tbody>
</table>

Solution

\[ A' = 2.2954 - 2.2626 \psi + 4.4395 \psi^2 - 2.9825 \psi^3 \]
\[ B' = -0.4193 - 1.9014 \psi + 3.3416 \psi^2 - 2.0409 \psi^3 \]
\[ C' = 0.1117 + 0.0553 \psi - 0.1468 \psi^2 + 0.1145 \psi^3 \]

\[ N_{ReP} = \frac{928 \rho_f v_{sl} d_s}{\mu} \]

\[ f_p = 10^A \left( A' + B' \log(N_{ReP}) + C' [\log(N_{ReP})]^2 \right) \]

\[ \nu_d = 1.89 \sqrt{\frac{d_s}{f_p} \left( \frac{\rho_s - 7.48 \rho_f}{7.48 \rho_f} \right)} \]

\[ A = \frac{\pi (d_a^2 - d_b^2)}{4} \]

\[ v_{tr} = \frac{\pi d_h^2}{4C_p A} \left( \frac{ROP}{3,600} \right) \]

\[ v_{min} = v_{sl} + v_{tr} \]

\[ q_{min} = 3.1167 v_{min} A \]

(Continued)
3.3 PRESSURE REQUIREMENTS

The selected mud pump should also be capable of providing pressure that is strong enough to overcome the total pressure loss and pressure drop at the bit in the circulating system at the total hole depth. The pressure loss depends on the mud properties, the drill string configuration, the borehole geometry, and the mud flow rate. The pressure drop at the bit should be optimized based on the total pressure loss in the system to maximize bit hydraulics. Therefore, extreme borehole architecture and condition should be considered.

3.3.1 Extreme Borehole Configurations

Maximum pressure loss normally occurs when the total hole depth is reached. At this point, the drill string and the open hole section assume their longest values. The borehole configuration is shown in Figure 3.3. To perform pressure loss calculations, it is convenient to put the dimension (lengths and diameters) data along the circulating path in the graph.

3.3.2 Extreme Borehole Conditions

The maximum circulating pressure normally occurs at the total depth with extreme borehole conditions. These conditions include the use of a mud flow rate higher than normal to clean the hole. Different mud properties are used, and the mud weight is increased before tripping out the drill string. These extreme parameter values should be marked in the borehole configuration graph for pressure loss calculations.

Illustrative Example 3.1 (Continued)

Table 3.3 Summary of Calculated Results

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Cuttings Size (in)</th>
<th>Slip Velocity (ft/s)</th>
<th>Transport Velocity (ft/s)</th>
<th>Mud Velocity (m/s)</th>
<th>Mud Flow Rate (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>37</td>
<td>0.26</td>
<td>6.53</td>
<td>0.58</td>
<td>0.18</td>
</tr>
<tr>
<td>140</td>
<td>427</td>
<td>0.23</td>
<td>5.93</td>
<td>0.49</td>
<td>0.15</td>
</tr>
<tr>
<td>7,000</td>
<td>2,134</td>
<td>0.20</td>
<td>5.08</td>
<td>0.41</td>
<td>0.13</td>
</tr>
<tr>
<td>10,000</td>
<td>3,048</td>
<td>0.30</td>
<td>7.62</td>
<td>0.55</td>
<td>0.17</td>
</tr>
</tbody>
</table>
3.3.3 Circulating Pressure

The maximum expected circulating pressure is the total frictional pressure loss and pressure drop at the bit at the total hole depth. The frictional pressure loss depends on the fluid properties, the flow velocity, the flow regime, and the length of the flow path. Under normal drilling conditions, turbulent flow exists inside the surface equipment, the drill pipe, the drill collar, and the annulus outside the drill collar. Laminar flow normally exists in the annulus outside the drill pipe. The pressure loss in
turbulent flow is usually higher than that in laminar flow. For the purpose of pump selection, assuming turbulent flow throughout the circulating system will result in conservative values of pressure losses.

This section presents the analytical method used for predicting the pressure losses in the drill string and in the annulus, as well as considerations for pressure drop at the bit. The length of the surface equipment is considered to be a small fraction of that of the drill string. Necessary hydraulics models were presented in Chapter 2. For directional and horizontal drilling, the pressure losses through the MWD and LWD tools are considered to be negligible. The pressure drop at the mud motor is considered as a specific value between 200 psi and 600 psi, depending on motor size.

However, the pressure drop at the bit is not calculated with Eq. (2.64) in the process of pump selection. For the optimum bit hydraulics, the pressure drop at the bit should be selected based on the total pressure loss in the system. According to the maximum bit hydraulic horsepower criterion (see Chapter 4), the following relation should be held:

\[
\Delta p_b = \frac{m}{m+1} p_p
\]  

(3.1)

where \( p_p \) is the pump pressure in psi or Pa, and \( m \) is the flow rate exponent. If the Blasius correlation is used for friction factor determination, Eq. (3.2) shows \( m = 1.75 \). However, according to the maximum jet impact force criterion (see Chapter 4), the following relation should be held:

\[
\Delta p_b = \frac{m}{m+2} p_p
\]  

(3.2)

3.3.4 The Minimum Required Pressure

The minimum required pump pressure is expressed as

\[
p_p = \Delta p_d + \Delta p_b
\]  

(3.3)

where

\[
\Delta p_d = \text{the total frictional pressure loss (parasitic pressure)}
\]

in psi or N/m\(^2\)—that is,

\[
\Delta p_d = \sum_{i=1}^{n} p_{\phi i}
\]
Combining Eqs. (3.1) and (3.3), the following relation is derived for the maximum bit hydraulic horsepower criterion:

\[ \Delta p_d = \frac{1}{m+1} p_p \]  

(3.4)

Combining Eqs. (3.2) and (3.3), the following relation is derived for the maximum jet impact force criterion:

\[ \Delta p_d = \frac{2}{m+2} p_p \]  

(3.5)

From which the expressions for the required pump pressure are

\[ p_p = (m + 1) \Delta p_d \]  

(3.6)

and

\[ p_p = \frac{m + 2}{2} \Delta p_d \]  

(3.7)

for the maximum bit hydraulic horsepower criterion and the maximum jet impact force criterion, respectively.

**Illustrative Example 3.2**

For the data in Illustrative Example 3.1 and the additional data given in Figure 3.4, determine the minimum required pump pressure. Assume the maximum mud weight of 12 ppg (1,440 kg/m³), the maximum plastic viscosity of 15 cp (0.015 Pa-s), the maximum yield point of 10 lb/100 ft² (4.78 Pa), pipe wall roughness of 0.00025 in. (0.00635 mm), pressure drop at the mud motor of 200 psi (1,379 kPa), and a mud flow rate of 300 gpm (1.14 m³/min).

**Solution**

This problem is solved using the spreadsheet program *Pump Pressure.xls* that is attached to this book. To calculate the required pump pressure using Table 3.4, (1) select a unit system, (2) update the data in the Input Data column, and (3) click on the Solution button and obtain the result. The result is summarized in Table 3.5 for the maximum bit hydraulic horsepower criterion. It indicates that the required pressure is 3,461 psi (23.86 MPa).

(Continued)
Illustrative Example 3.2 (Continued)

Figure 3.4 Example of borehole configuration at the total depth.

Table 3.4 Part of the spreadsheet program *Pump Pressure.xls*

<table>
<thead>
<tr>
<th>Input Data</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole depth</td>
<td>10,000 ft</td>
</tr>
<tr>
<td>Open hole diameter</td>
<td>7.875 in</td>
</tr>
<tr>
<td>Open hole roughness</td>
<td>0.05 in</td>
</tr>
<tr>
<td>Cased hole depth</td>
<td>7,000 ft</td>
</tr>
<tr>
<td>Cased hole diameter</td>
<td>7.921 in</td>
</tr>
</tbody>
</table>
Table 3.4 (Continued)

<table>
<thead>
<tr>
<th>Input Data</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe roughness</td>
<td>0.0025 in</td>
</tr>
<tr>
<td>Length of drill collar 1</td>
<td>60 ft</td>
</tr>
<tr>
<td>OD of collar 1</td>
<td>7.000 in</td>
</tr>
<tr>
<td>ID of collar 1</td>
<td>3.000 in</td>
</tr>
<tr>
<td>Length of drill collar 2</td>
<td>0 ft</td>
</tr>
<tr>
<td>OD of collar 2</td>
<td>6.250 in</td>
</tr>
<tr>
<td>ID of collar 2</td>
<td>2.500 in</td>
</tr>
<tr>
<td>Length of drill collar 3</td>
<td>250 ft</td>
</tr>
<tr>
<td>OD of collar 3</td>
<td>5.750 in</td>
</tr>
<tr>
<td>ID of collar 3</td>
<td>3.000 in</td>
</tr>
<tr>
<td>Drill pipe OD</td>
<td>5.000 in</td>
</tr>
<tr>
<td>Drill pipe ID</td>
<td>4.000 in</td>
</tr>
<tr>
<td>Mud weight</td>
<td>11 ppg</td>
</tr>
<tr>
<td>Plastic viscosity</td>
<td>5 cp</td>
</tr>
<tr>
<td>Yield point</td>
<td>5 lb/100 ft²</td>
</tr>
<tr>
<td>Mud flow rate</td>
<td>300 gpm</td>
</tr>
<tr>
<td>Pressure drop at mud motor</td>
<td>200 psi</td>
</tr>
<tr>
<td>Flow rate exponent</td>
<td>1.75 m</td>
</tr>
</tbody>
</table>

Solution

\[
p = \frac{q}{2.448(d_o^2 - d_i^2)}
\]

\[
d_e = 0.816(d_o - d_i)
\]

\[
\mu_s = \mu_p + \frac{6.66 \tau_d}{\mu_a}
\]

\[
N_{Re} = \frac{928 \rho_f \bar{v}_d}{\mu_a}
\]

\[
f = \left( -4 \log \left( \frac{e}{3.7065} - \frac{5.0452}{N_{Re}} \right) \right) \log \left( \frac{e^{1.098}}{2.8257} + \left( \frac{7.149}{N_{Re}} \right)^{0.8981} \right)^{-2}
\]

\[
\frac{dp_f}{dL} = \frac{f \rho_f \bar{v}^2}{25.8 d} \arcsin \theta
\]

\[
p_f = \left( \frac{dp_f}{dL} \right) L
\]

\[
\Delta p_f = \sum_{i=1}^{n} p_{fi}
\]

\[
p_f = (m + 1) \Delta p_d
\]

\[
p_f = \frac{n_{x+y}}{2} \Delta p_d \pi
\]

Mud Pumps 71

(Continued)
**3.4 HORSEPOWER REQUIREMENTS**

In rotary drilling, the engines that supply power are rated on output horsepower, sometimes called brake horsepower. Fluid pumps that receive power are rated on the basis of input horsepower. For this reason, a 1,600-hp pump classification means that the horsepower fed into the pump should not exceed 1,600. Output horsepower from pumps used in rotary drilling is determined from charts of maximum permissible surface pressure and maximum circulation rate.

Mud pumps are rated by horsepower \( P_H \) and the maximum working pressure \( P_{pmw} \). Figure 3.5 shows a theoretical pump performance curve. The mud hydraulic horsepower from the pump is expressed as (Moore, 1986)

\[
P_h = \frac{q p}{1,714}
\]  

where

- \( P_h \) = hydraulic horsepower, hp
- \( q \) = mud flow rate, gpm or m\(^3\)/min
- \( p \) = pump pressure, psi or kPa
The constant 1,714 in U.S. units is 44.14 in SI units.

For a given pump having a horsepower rating \( P_H \), the value of the right-hand side of Eq. (3.8) should not exceed \( P_H \); that is, \( P_h < P_H \). If a pump runs at the maximum working pressure \( P_{pm} \), the maximum available flow rate is expressed as

\[
q_{max} = \frac{1,714 E_p P_H}{P_{pm}}
\]  
(3.9)

where

- \( q_{max} \) = maximum mud flow rate, gpm or m³/min
- \( P_H \) = Horsepower rating of pump, hp
- \( E_p \) = pump efficiency, dimensionless
- \( P_{pm} \) = maximum working pressure of pump, psi or MPa

If a pump runs at a flow rate \( q < q_{max} \), the maximum available pump pressure is expressed as

\[
p_{max} = \frac{1,714 E_p P_H}{q}
\]  
(3.10)

However, the pump pressure should always be kept lower than the maximum working pressure—that is, \( p_{max} < P_{pm} \).
Illustrative Example 3.3
For the data in Illustrative Examples 3.1 and 3.2, determine the required horsepower rating of the pump.

Solution
The pump should be able to provide adequate horsepower while drilling all hole sections. The extreme hole conditions occur when the surface hole and the total hole depth are drilled. Drilling the surface hole requires the highest mud flow, and drilling at the total depth requires the highest pump pressure.

Surface Hole Drilling. Illustrative Example 3.1 shows that the minimum required flow rate to drill the surface hole is 990 gpm (3.75 m³/min). The required pressure at the bottom of the hole section with 60 feet (18.3 m) of a 7-inch (178 mm) drill collar is calculated using the spreadsheet program Pump Pressure.xls. The result of the pressure loss is 364 psi (2,509 kPa). Considering a pressure drop at the bit of twice the pressure loss, the circulating pressure will be 1,092 psi (7,529 kPa). Substituting these data into Eq. (3.9) gives

\[ P_h = \frac{(990)(1,092)}{1,714} = 631 \text{ hp} \]

Drilling at the Total Depth. Using the flow rate of 350 gpm (1.325 m³/min) and the required pressure of 3,461 psi (23,863 kPa) calculated with the spreadsheet program Pump Pressure.xls, Eq. (3.9) gives

\[ P_h = \frac{(350)(3,641)}{1,714} = 743 \text{ hp} \]

Therefore, the minimum required horsepower rating of the pump is 743 hp.

3.5 CAPACITIES OF MUD PUMPS
The two types of piston strokes in mud pumps are the single-action piston stroke and the double-action piston stroke, which are shown in Figures 3.6 and 3.7. The double-action stroke is used for duplex (two pistons) pumps. The single-action stroke is used for triplex pumps. Normally, duplex pumps can handle higher flow rates, and triplex pumps can provide higher pressure. The discharged flow rate depends on several parameters, including the liner size, the rod size, the stroke length, the
pumping speed, and the volumetric efficiency. The rod size changes with the size of the liner. The pumping speed can be adjusted if diesel engines or DC motors are used as the prime movers. The volumetric efficiency varies with the fluid properties.

**Figure 3.6** Double-action stroke in a duplex pump.

**Figure 3.7** Single-action stroke in a triplex pump.
3.5.1 Triplex Pumps
Geometrical analysis allows for the following equation to be derived for triplex pumps (Guo et al., 2007):

\[ q_T = 0.01 e_v d^2 l N \]  \hspace{1cm} (3.11)

where

- \( q_T \) = flow rate of triplex pump, gpm or \( m^3/\text{min} \)
- \( e_v \) = volumetric efficiency, dimensionless
- \( d \) = piston diameter, in or m
- \( l \) = stroke length, in or m
- \( N \) = pumping speed, spm

The constant 0.01 in U.S. units is 2.3066 in SI units.

The pumped volume per stroke is

\[ q_S = \frac{e_v d^2 l}{4,118} \]  \hspace{1cm} (3.12)

where

- \( q_S \) = pumped volume per stroke, bbl or \( m^3 \)

The constant 4,118 in U.S. units is 0.4201 in SI units.

The input horsepower needed from the prime mover is expressed as

\[ HP = \frac{p d^2 l N}{168,067 e_m} \]  \hspace{1cm} (3.13)

where

- \( HP \) = pump horsepower, hp
- \( e_m \) = pump mechanical efficiency, dimensionless

The constant 168,067 in U.S. units is 18.98 in SI units.

3.5.2 Duplex Pumps
Geometrical analysis allows for the following equation to be derived for duplex pumps (Guo et al., 2007):

\[ q_D = 0.0068 e_v (2d_1^2 - d_2^2) l N \]  \hspace{1cm} (3.14)

where

- \( q_D \) = flow rate of duplex pump, gpm or \( m^3/\text{min} \)
- \( d_1 \) = piston diameter, in or mm
- \( d_2 \) = rod diameter, in or mm
The constant 0.0068 in U.S. units is $1.57 \times 10^{-9}$ in SI units.

The pumped volume per stroke is

$$q_S = \frac{e_vd^2l}{5,912}$$

(3.15)

where

$q_S =$ pumped volume per stroke, bbl or m$^3$

The constant 5,912 in U.S. units is 0.6069 in SI units.

The input horsepower needed from the prime mover is expressed as

$$HP = \frac{p(2d_1^2 - d_2^2)lN}{252,101\epsilon_m}$$

(3.16)

The constant 252,101 in U.S. units is $2.8 \times 10^{10}$ in SI units.

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**Illustrative Example 3.4**

Two identical pumps are considered for drilling the well shown in Illustrative Example 3.2. These pumps are the TSC WF700 triplex pumps, each having a stroke length of 8.5 in. (0.216 m). Table 3.6 provides the pump specification data given by the manufacturer.

The pump can run at the maximum speed of 150 spm with piston diameters from 4 in. to 7 in. (0.108 m to 0.178 m). Assuming that the volumetric efficiency and mechanical efficiency are 0.95 and 0.9, respectively, if the flow rate of 350 gpm (1.325 m$^3$/min) is desired with 4.5-in. (0.114 m) liners, what is the required pump speed? What is the total input horsepower needed from the prime movers?

**Solution**

Equation (3.11) gives

$$N = \frac{qT}{0.01\epsilon_v d^2 l}$$

$$= \frac{350/2}{0.01(0.95)(4.5)^2(8.5)}$$

$$= 107 \text{ spm}$$

(Continued)
This chapter presented theory and procedures for selecting mud pumps. Extreme borehole geometries and mud properties should be considered for calculating the minimum required flow rate, pressure, and horsepower. Safety factors should be applied.
REFERENCES

PROBLEMS
3.1 Solve the problem in Illustrative Example 3.1 with a cuttings concentration value of 10% in all hole sections.
3.2 Solve the problem in Illustrative Example 3.2 with a mud flow rate of 300 gpm.
3.3 Solve the problem in Illustrative Example 3.3 with a mud flow rate of 300 gpm.
3.4 Solve the problem in Illustrative Example 3.4 with a liner size of 4 in.