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MINIMUM VOLUMETRIC REQUIREMENTS IN AERATED DRILLING

A FIELD OPERATIONS MANUAL

Work Performed for the Department of Energy
Under Contract No. DE-AC19-79BC10079

Date Published—December 1982

The University of Tulsa
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MINIMUM VOLUMETRIC REQUIREMENTS IN AERATED DRILLING

A FIELD OPERATIONS MANUAL

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UNITED STATES DEPARTMENT OF ENERGY

FOREWORD

This Field Operations Manual is the culmination of research covering particle transport for aerated drilling operations. It was the intended product when the contract with The University of Tulsa was approved and funded by the Department of Energy. The research work was performed in a diligent, skillful manner and is documented in the DOE publications for this contract.

It is believed that use of this Field Operations Manual will provide drillsite personnel with a simple method of determining the proper amount of air, mist or foam that should be used in various drilling situations. It is unlikely that the commonly used (and usually successful) trial-and-error methods will be displaced, but perhaps this document will serve to reduce the use of excessive air volumes which increase cost and wellbore deterioration.

C. Ray Williams
Technical Project Officer

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CHAPTER 1

INTRODUCTION

This Field Operations Manual provides drilling engineers a means of making quick, graphical determinations of gas (air) and liquid volumetric requirements in air, foam, and mist drilling. A model for predicting correct air (gas) volume requirements in air drilling has been developed[1]. It includes a complete analysis of pressures throughout the system, offers flexibility in selection of wellhead pressure and air flow rate, and is primarily graphical. For the details of the model, its theoretical and experimental basis, Reference 1 should be consulted. Charts are presented for sandstone, shale and limestone formations. Gas specific gravity (SGG) values of 0.8 and 1.0 were used. The penetration rate and hole size considered were 60 ft/hr and 7.875 inches, respectively. Particle sizes of 0.1 and 0.2 inches were employed.

A model has also been developed for predicting minimum volumetric requirements for foam and mist drilling operations[2]. It accounts for frictional losses due to the solid-phase, pressure drop across bit nozzles and particle settling velocities. Reference 2 should be consulted for the details of the model, and its theoretical and experimental basis. The technique offers a high degree of flexibility in the selection of wellhead injection pressures and volumetric requirements. Actual field application of this work can be accomplished by two different methods depending on compressor specifications. These are the "Variable Back Pressure" and "Constant Back Pressure" schedules. They are primarily graphical.

Charts are presented for 7.875 and 9.00 inch hole sizes, drilled cutting sizes of 0.50, 0.75, and 1.00 inch and penetration rates ranging from 30 to 120 ft/hr. Results show that volumetric requirements increase with increasing hole size, increasing depth, and increasing particle size. Increases in penetration rate cause minor increases in volumetric requirements.

The technique assumes 0.55 minimum bottomhole and 0.96 maximum annular foam qualities. Results also show that all foam drilling and well cleanout operations can be accomplished within the laminar flow region if the 0.55 minimum bottomhole and 0.96 maximum annular foam qualities are adhered to. In order to maintain a bottomhole foam quality of 0.55 or more and still reach reasonable depths, annular back pressures greater than atmospheric pressure are needed. However, for a constant depth, as back pressure increases, both wellhead injection pressure and gas flow rate must be increased and liquid flow rate decreased. It is recommended that the surface active agent (foaming agent) should constitute one percent of the liquid volume.

The main advantage of these techniques over the currently practiced trial and error methods in aerated drilling is the prevention of the use of excess air (gas) and/or foamer solution while the hole is still in gauge. If these results can be realized, problems such as hole enlargement, sloughing shale, and wellbore collapse can be minimized and drilling costs will be reduced.

All of the charts presented in this manual assume regular bits with nozzles of 28/32 inches each. For large bit nozzle sizes used in aerated drilling, pressure drop across such nozzles is negligible in comparison to total system losses[2]. Thus the charts are also applicable to conditions where no nozzles are involved.

Example problems that illustrate field applications of the models developed are presented in Chapter 2.

CHAPTER 2

FIELD APPLICATION

A. Minimum Volumetric Requirements for Air (Gas) Drilling (Reference 1)

In this section, two example problems and their corresponding solutions are presented to illustrate how the charts given in Figures 2.1 and A.1 to A.3 can be used in determining volume requirements in air (gas) drilling.

Example Problem A.1

A well is to be drilled in an area where the formation is shale. A 7-7/8" hole is being programmed to reach 11,000' using a 4-1/2" drill pipe and a regular bit with three nozzles of 28/32" each. The drilling supervisor wants to know what the drilling schedule should be for air volume requirements and standpipe pressure, if the desired penetration rate is estimated at 60 ft/hr. It can be assumed that the average particle size for shale is approximately 0.2 inches.

Solution

The schedule for air volume requirements and standpipe pressure can be estimated using Figure 2.1. Table 2.1 presents the results obtained for Figure 2.1.

Table 2.1
Graphical Solution of Problem A.1

Well Depth (ft)	Standpipe Pressure (psig)	Air Flow Rate (SCFM)
0- 2,500	50	888
2,500- 3,500	75	1,043
3,500- 5,000	100	1,182
5,000- 6,300	125	1,295
6,300- 7,500	150	1,440
7,500- 8,500	175	1,560
8,500- 9,500	200	1,662
9,500-11,000	225	1,782

Example Problem A.2

A well is going to be drilled in an area where the formation, is shale. A 7-7/8" hole is programmed to reach 11,000' using a 4-1/2" drill pipe and a regular bit with three nozzles of 28/82" each. The assumptions and requirements of Problem A.1 also apply here. However, the compressor can only be operated in stages of 100 psig.

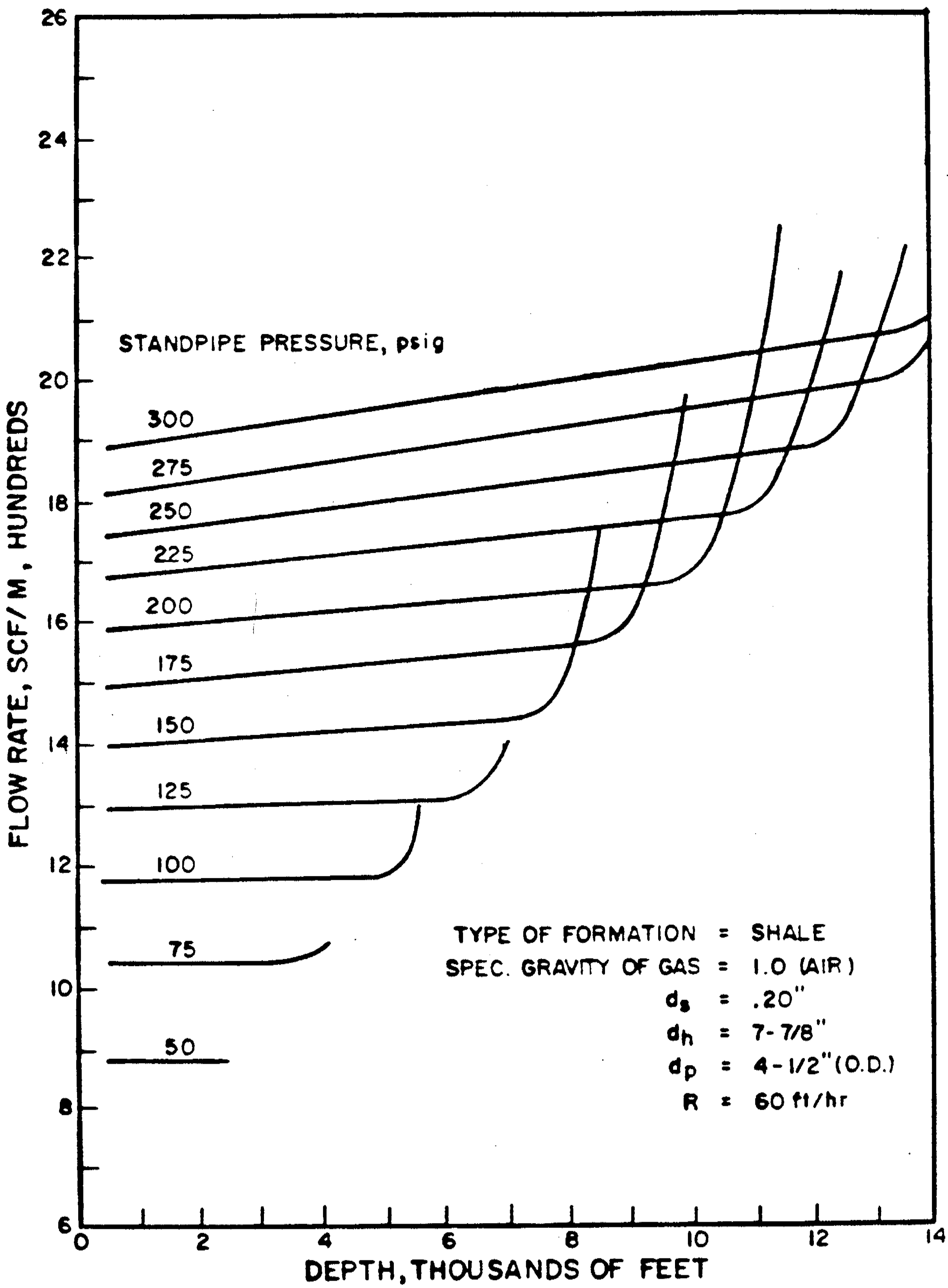

Figure 2.1: Volume Requirements Versus Depth for Shale Formation (SGG : 1.0, ds = 0.20 in.)

Solution

The schedule for air volume requirements and standpipe pressure for the problem can also be estimated from Figure 2.1 and are shown in Table 2.2.

Table 2.2
Graphical Solution of Problem A.2

Well Depth (ft)	Standpipe Pressure (psig)	Air Flow Rate (SCFM)
0- 5,000	100	1,182
5,000- 9,500	200	1,662
9,500-11,000	300	2,090

These schedules are also subject to the compressor specifications. If they cannot be met, then the appropriate ones can be selected based on the compressor specifications and drilling conditions.

The charts for the other operating conditions are given in Figures A.1 through A.3 of Appendix A.

B. Minimum Volumetric Requirements in Foam and Mist Drilling and Well Cleanout Operations (Reference 2)

The application of this work to actual drilling and well cleanout operations can be accomplished by two different methods, depending on compressor specifications. These methods can be called the "Variable Back Pressure" and the "Constant Back Pressure" schedules. Both are graphical which enables the drilling engineer to use them in the field without access to a computer.

Example Problem B.1

A well is to be drilled to a depth of 10,000 feet using a 4 1/2 inch O.D. drill pipe and a regular bit with three nozzles of 28/32 inches each. The drill pipe's internal diameter is 3.76 inches and the desired hole size is 7.875 inches. The drilling engineer wants to know what the drilling schedule should be for the air and liquid (foamer solution) volume requirements and the wellhead injection pressure for a desired penetration rate of 60 feet/hour. It can be assumed that the average drill cutting size to be transported is 0.5 inch with a specific gravity of 2.7.

Solution

a. Variable Back Pressure Method: The schedule for the volumetric requirements and injection pressure can be read directly from Figure 2.2. The procedure involves the following steps:

1. Start with the lowest compressor pressure specification available and move horizontally to a back pressure that yields the greatest depth. Note the depth and back pressure.

2. Move vertically down to the air and liquid charts and read off the air and liquid volume flow rates corresponding to the depth and back pressure of Step 1.

3. Repeat Steps 1 and 2 for higher compressor pressures until the desired depth is reached.

The predictions obtained from Figure 2.2 are shown in Table 2.3.

Table 2.3
Graphical Solution of Problem B.1 Using Variable Back Pressure Method

Wellhead Injection Pressure (psig)	Annular Back Pressure (psia)	Well Depth (ft)	Air Flow Rate (SCF/M)	Liquid Flow Rate (GPM)
100	20	0- 1,500	200	43
200	40	1,500- 2,500	380	41
300	60	2,500- 4,000	590	42
400	80	4,000- 5,500	800	42
500	100	5,500- 7,500	1,030	42
600	120	7,500-10,000	1,260	43

This schedule shows that the variable back pressure approach can be effectively carried out with a constant liquid flow rate. Thus, the only task left to the drilling personnel is the adjustment of compressor outputs to meet the required air flow rates.

b. <u>Constant Back Pressure Method</u>: The procedure involved in this method is similar to that of the variable back pressure approach; however, in this case a constant back pressure curve is used.

The predictions for the example problem using the 120 psia back pressure curve in Figure 2.2 are presented in Table 2.4.

Table 2.4
Graphical Solution of Problem B.1 Using Constant Back Pressure Method

Wellhead Injection Pressure (psig)	Annular Back Pressure (psia)	Well Depth (ft)	Air Flow Rate (SCF/M)	Liquid Flow Rate (GPM)
300	120	0- 1,750	540	18
400	120	1,750- 3,250	700	23
500	120	3,250- 5,250	950	32
600	120	5,250-10,000	1,260	43

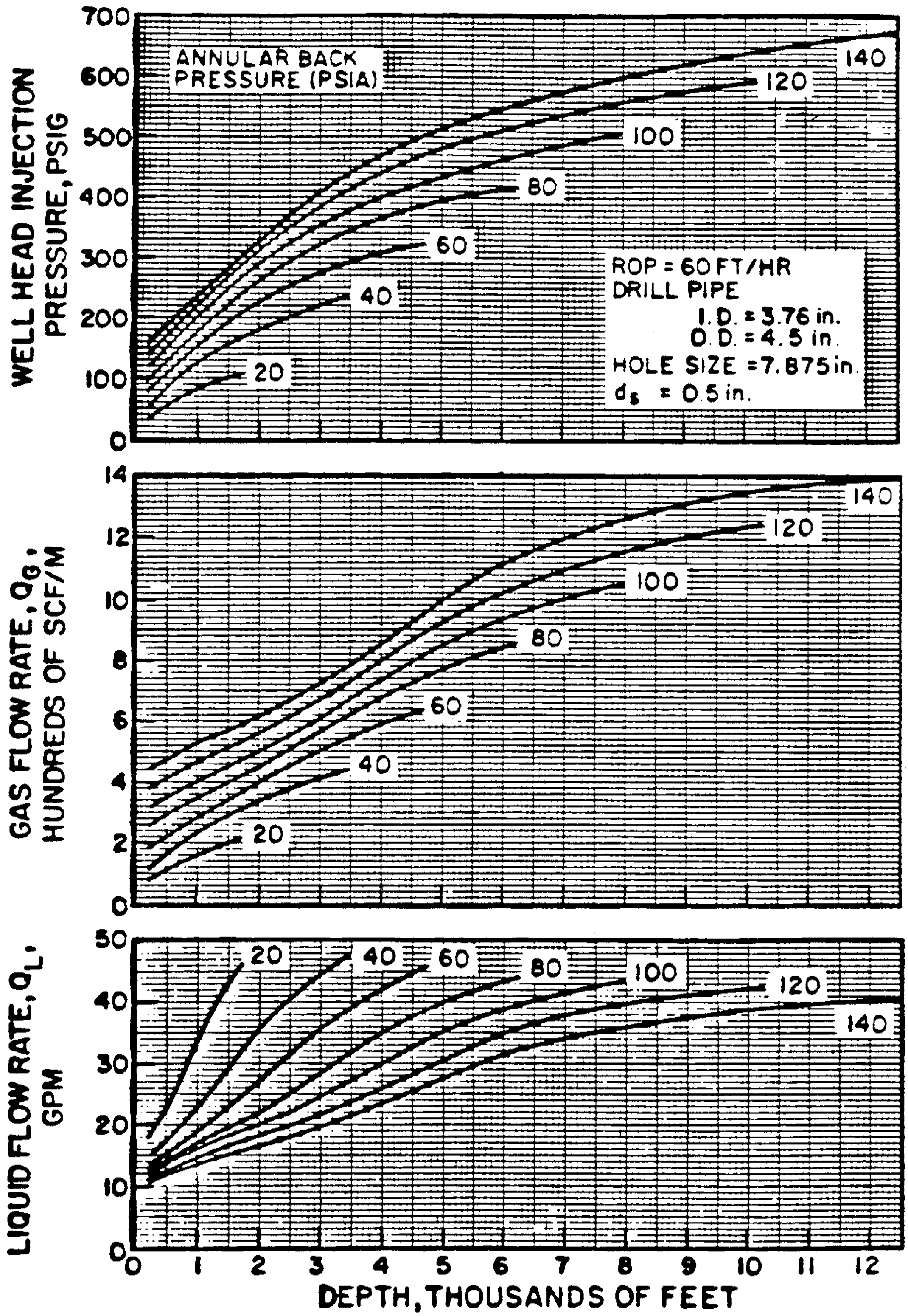

Figure 2.2: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 60 ft/hr; Particle Size = 0.5 in.)

The constant back pressure curve selected should be the one that terminates at or beyond the depth desired.

Example Problem B.2

The problem of interest here is similar to Example B.1. However, the desired depth is 5,000 feet. The assumptions of Example B.1 still hold.

Solution

a. Variable Back Pressure Method: The results obtained from Figure 2.2 are shown in Table 2.5.

Table 2.5
Graphical Solution of Problem B.2 Using Variable Back Pressure Method

Wellhead Injection Pressure (psig)	Annular Back Pressure (psia)	Well Depth (ft)	Air Flow Rate (SCF/M)	Liquid Flow Rate (GPM)
100	20	0- 1,500	200	43
200	40	1,500- 2,500	380	41
300	60	2,500- 4,000	590	42
400	80	4,000- 5,000	800	42

b. Constant Back Pressure Method: The predictions for this example problem will be made with 80 psia back pressure curve. The results obtained using Figure 2.2 are given in Table 2.6.

Table 2.6
Graphical Solution of Problem B.2 Using Constant Back Pressure Method

Wellhead Injection Pressure (psig)	Annular Back Pressure (psia)	Well Depth (ft)	Air Flow Rate (SCF/M)	Liquid Flow Rate (GPM)
200	80	0- 1,250	380	18
300	80	1,250- 2,500	520	26
400	80	2,500- 5,000	780	41

It should be noted that the schedules given are subject to the compressor specifications. Where they cannot be met, appropriate ones can be selected based on the compressor specifications and drilling conditions. Also, in developing the schedules for the example problem, it was assumed that surface losses are negligible. In situations where such losses are significant, they should be accounted for in order to accurately determine the actual injection pressure required.

The "Constant Back Pressure Method" requires less liquid volume than the "Variable Back Pressure Method" to reach a certain depth. Thus, it is a more economical approach.

Figures B.1 through B.15 of Appendix B are the charts for other operating conditions.

REFERENCES

1. Machado, C. J., Chi U. Ikoku, "Experimental Determination of Solids Friction Factor and Minimum Volumetric Requirements in Air or Gas Drilling," U. S. Department of Energy Topical Report Contract No. DE-AC19-79BC10079, August 1981, DOE/BC/10079-26(DE81026604), The University of Tulsa, Tulsa, Oklahoma, 1980.

2. Okpobiri, G. A., Chi U. Ikoku, "Experimental Determination of Solids Friction Factors and Minimum Volumetric Requirements In Foam and Mist Drilling and Well Cleanout Operations," U. S. Department of Energy Topical Report Contract No. AC19-79BC10079, September 1982, DOE/BC/10079-48 (DE82020945), The University of Tulsa, Tulsa, Oklahoma, 1982.

APPENDIX A

Charts for Minimum Volumetric Requirements for Air (Gas) Drilling

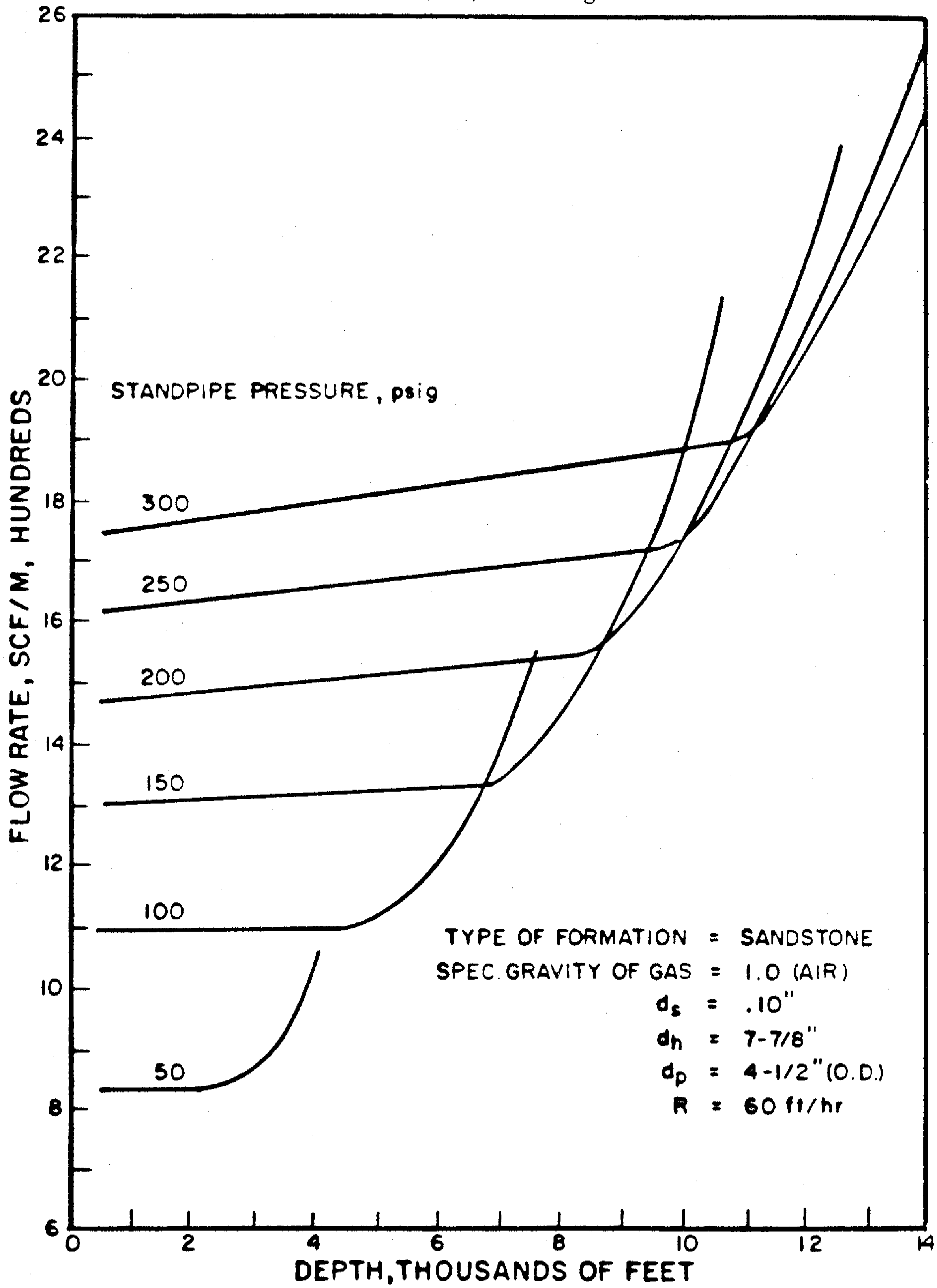

Figure A.1: Volume Requirements Versus Depth for Sandstone Formation (SGG = 1.0; ds = 0.10 in.)

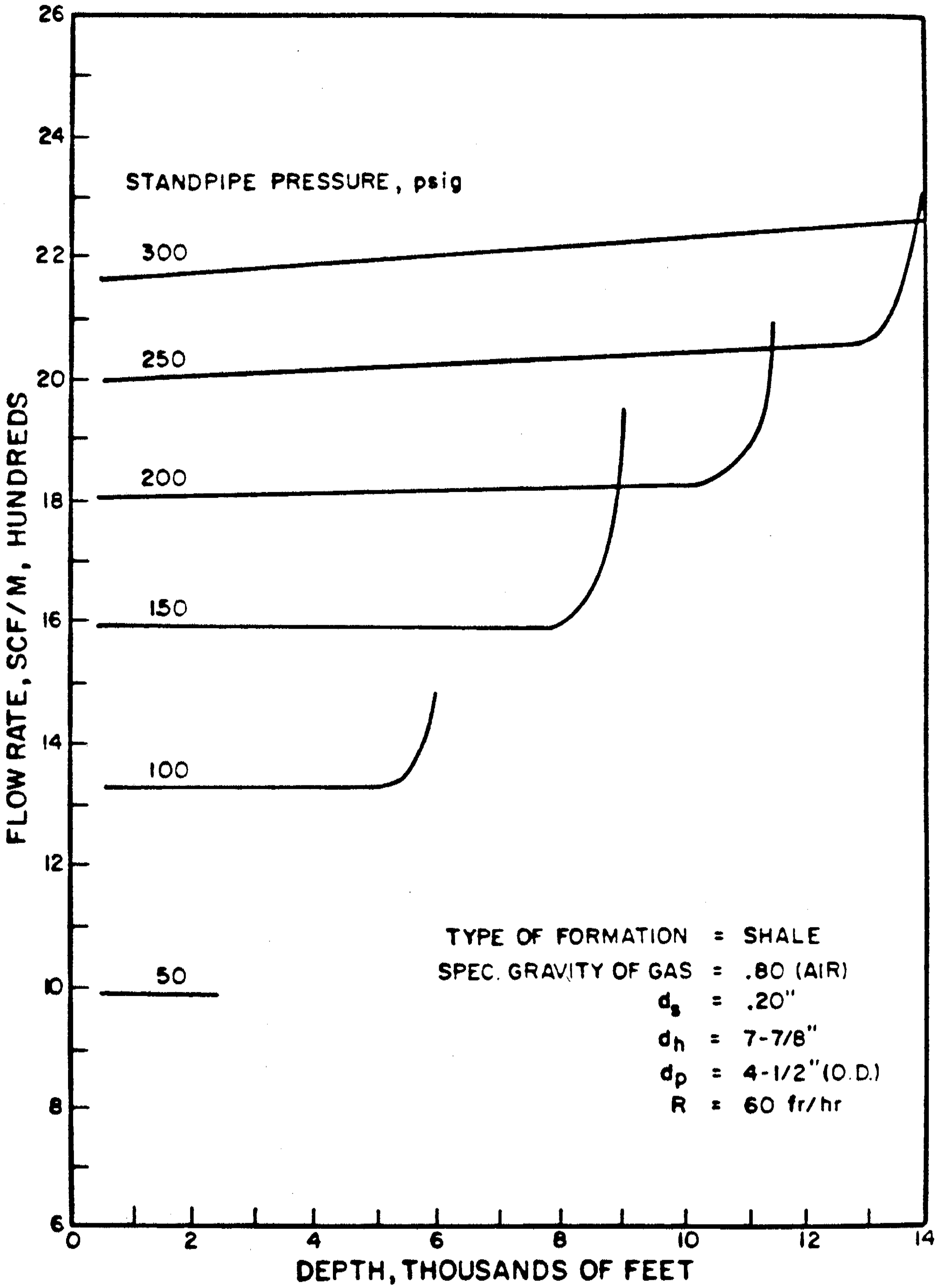

Figure A.2: Volume Requirements Versus Depth for Shale Formation (SGG = 0.8; ds = 0.20 in.)

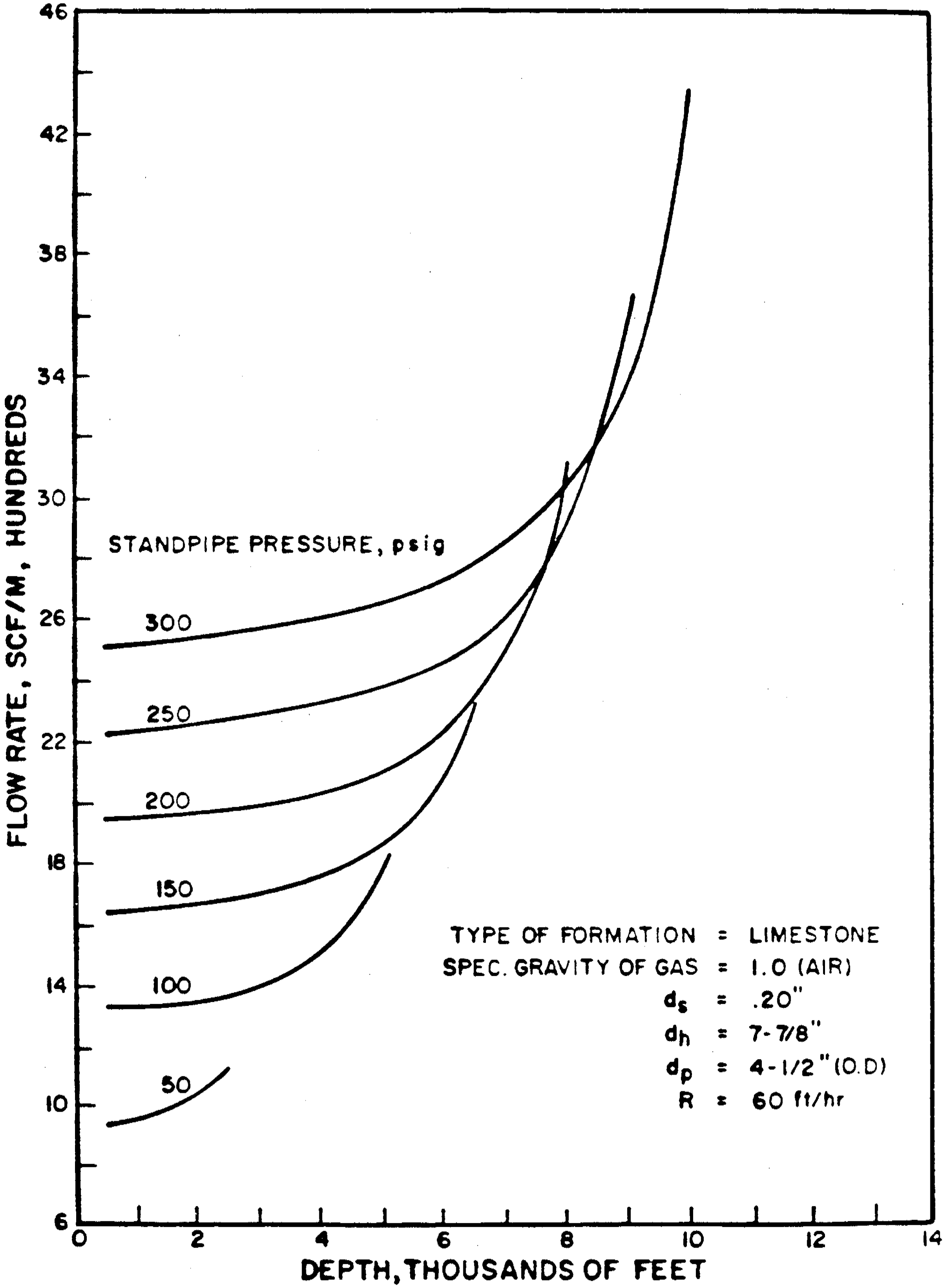

Figure A.3: Volume Requirements Versus Depth for Limestone Formation (SGG = 1.0; ds = 0.20 in.)

APPENDIX B

Charts for Volumetric Requirements in Foam and Mist Drilling and Well Cleanout Operations

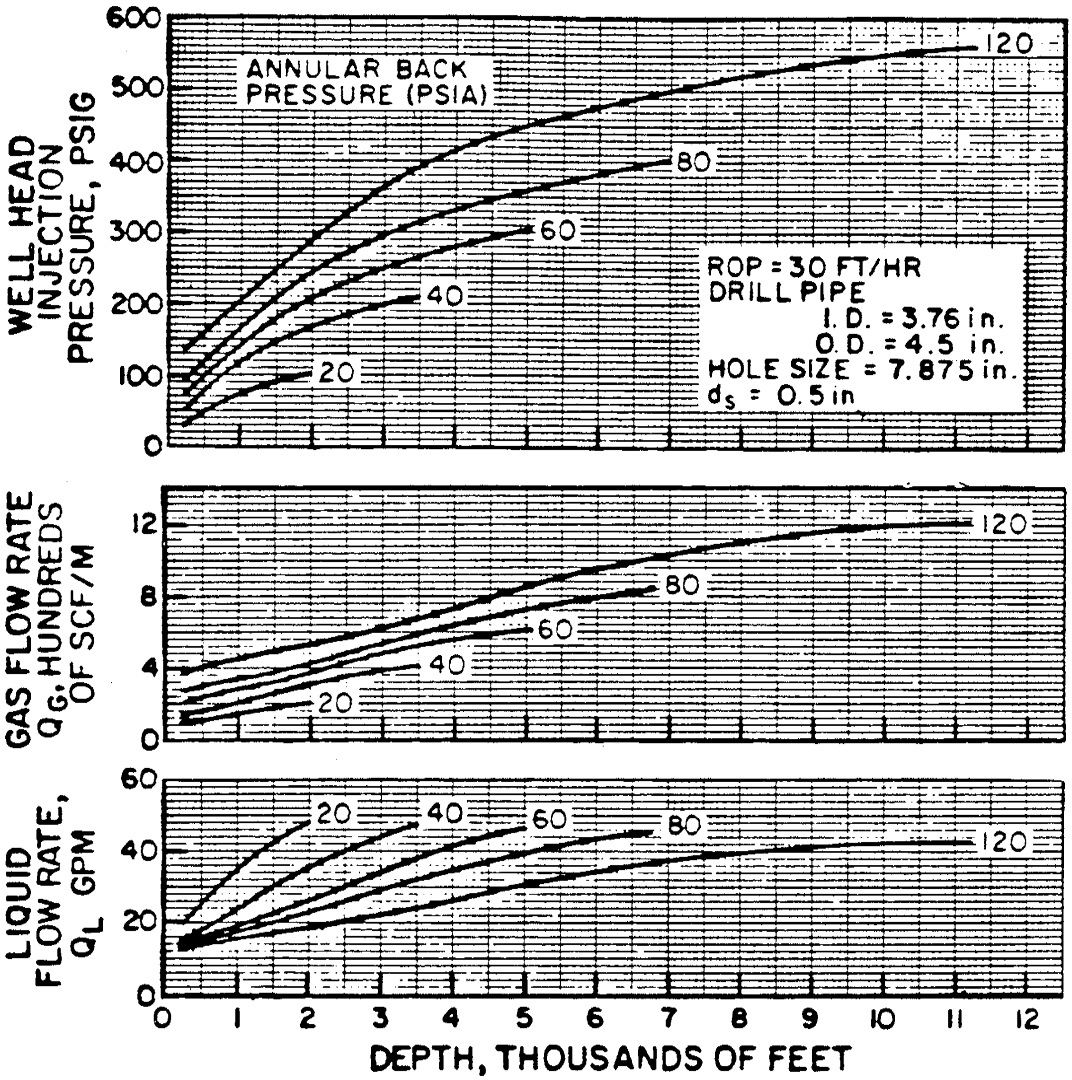

Figure B.1: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 30 ft/hr; Particle Size = 0.5 in.)

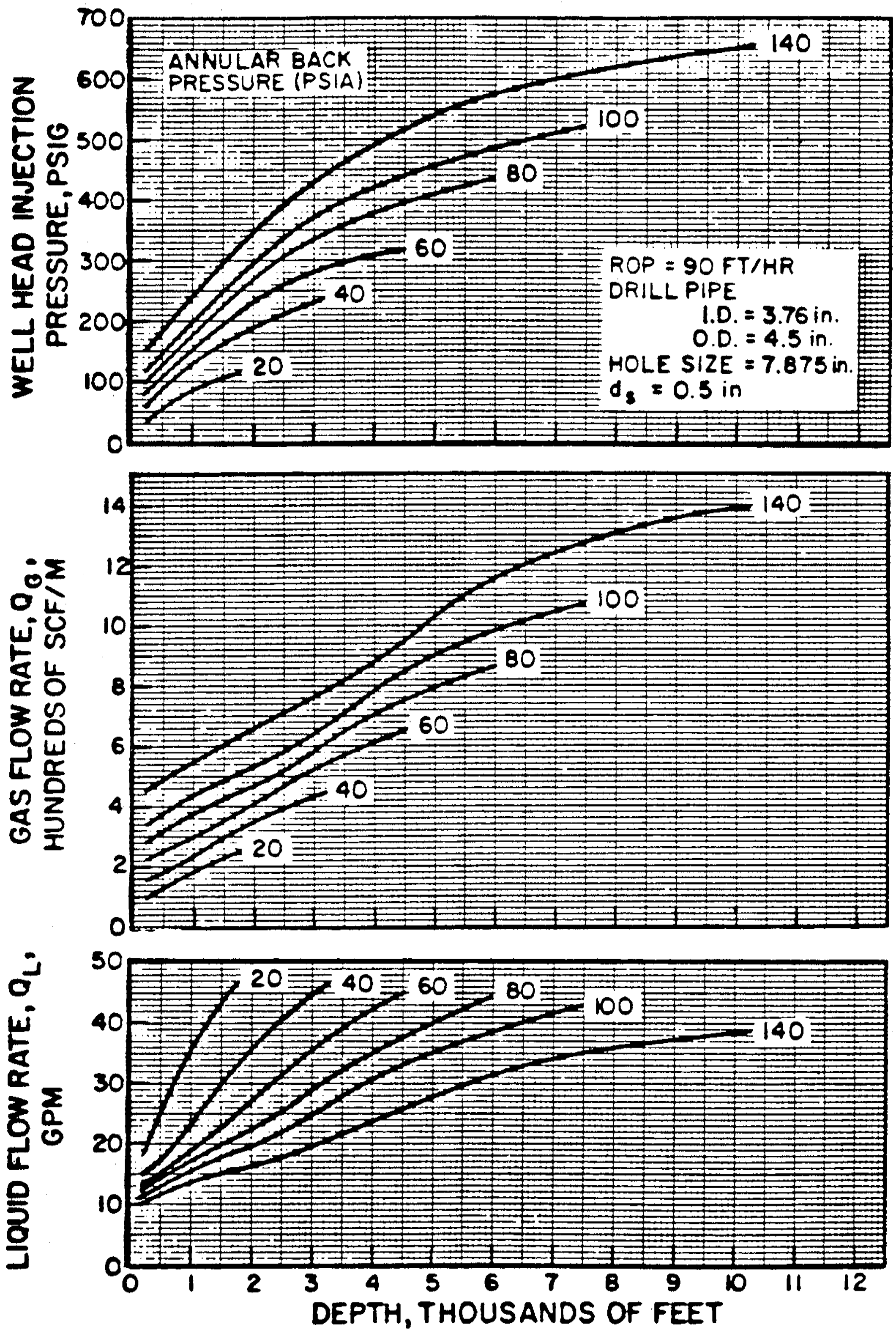

Figure B.2: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 90 ft/hr; Particle Size = 0.5 in.)

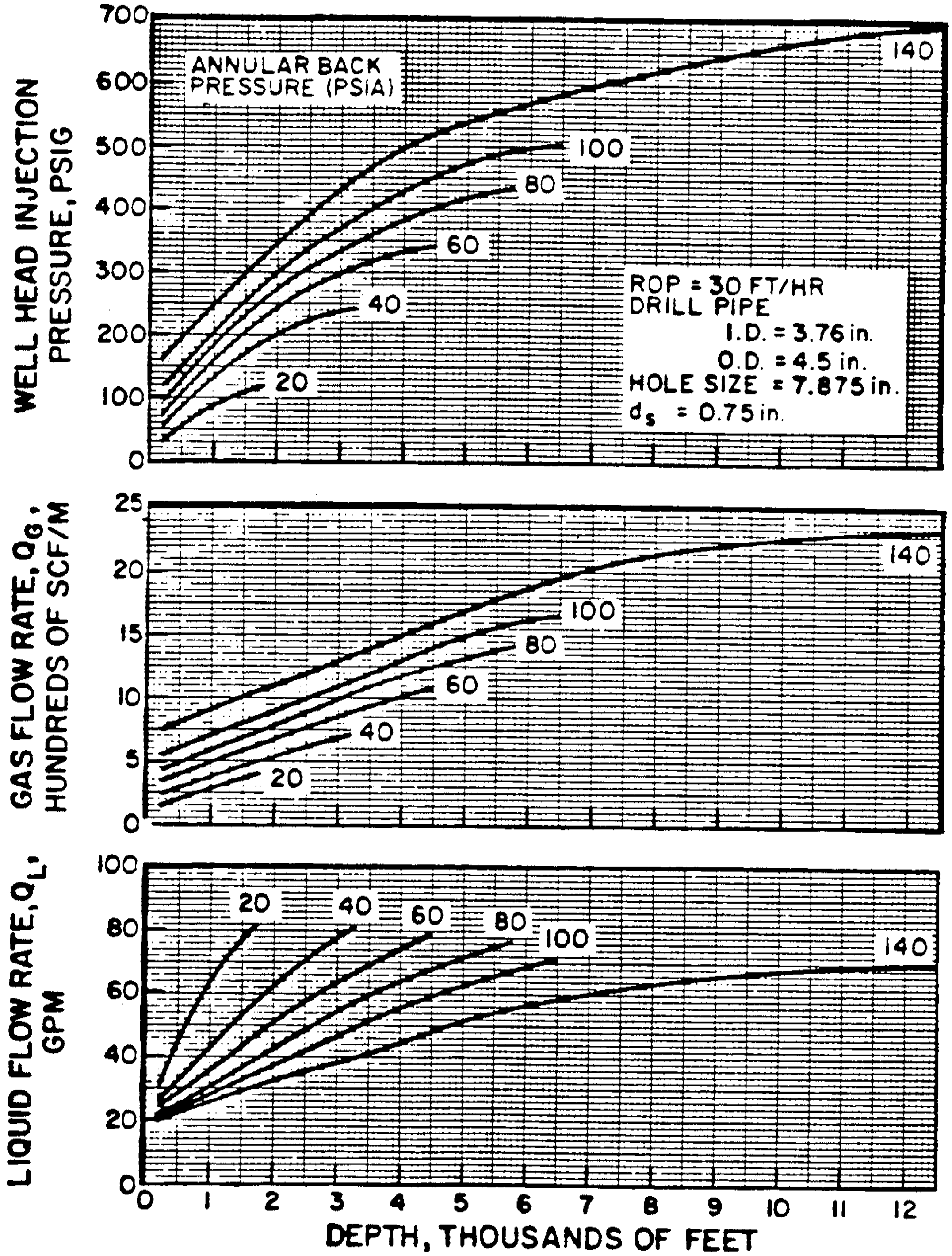

Figure B.3: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 30 ft/hr; Particle Size = 0.75 in.)

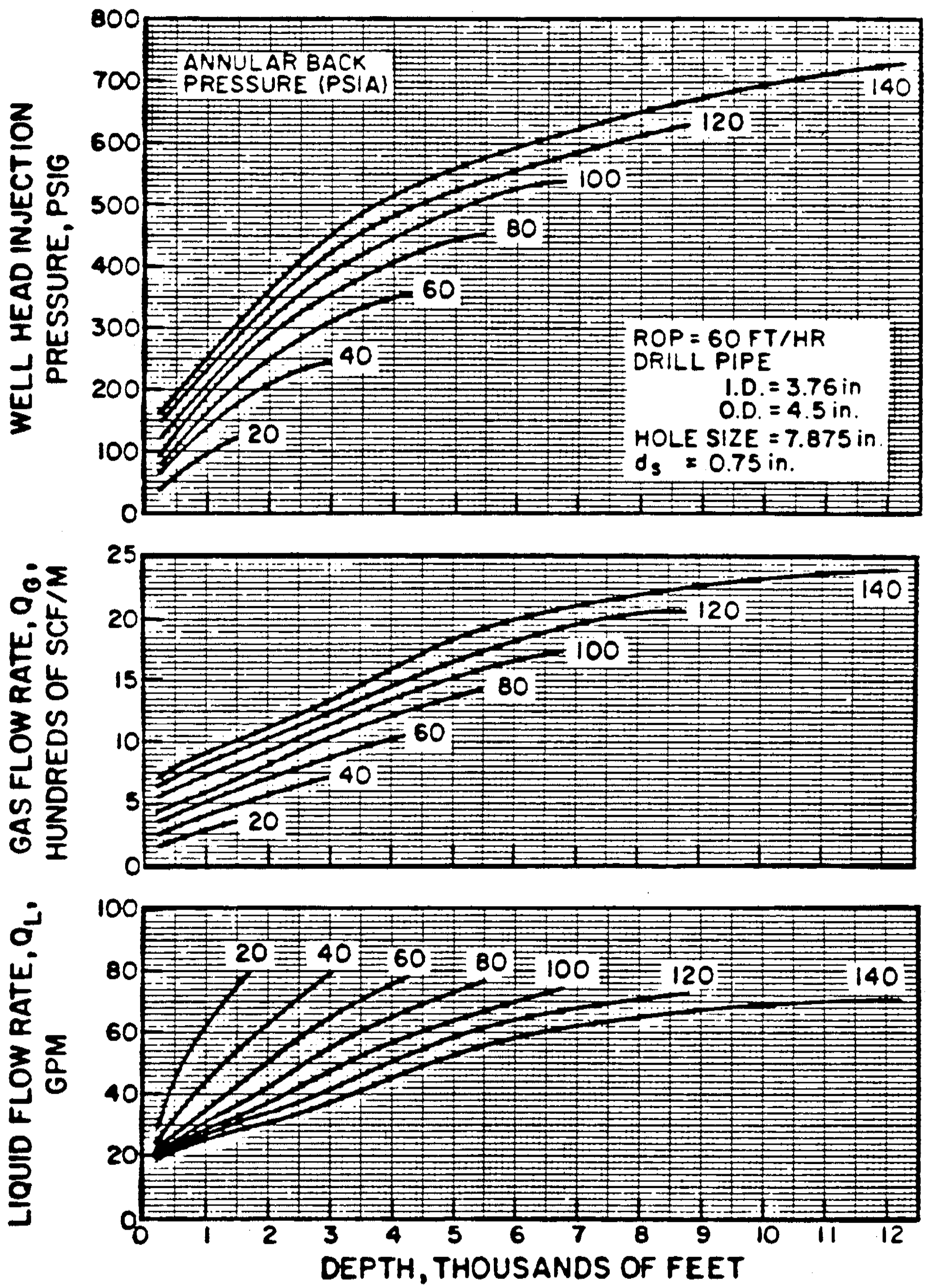

Figure B.4: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 60 ft/hr; Particle Size = 0.75 in.)

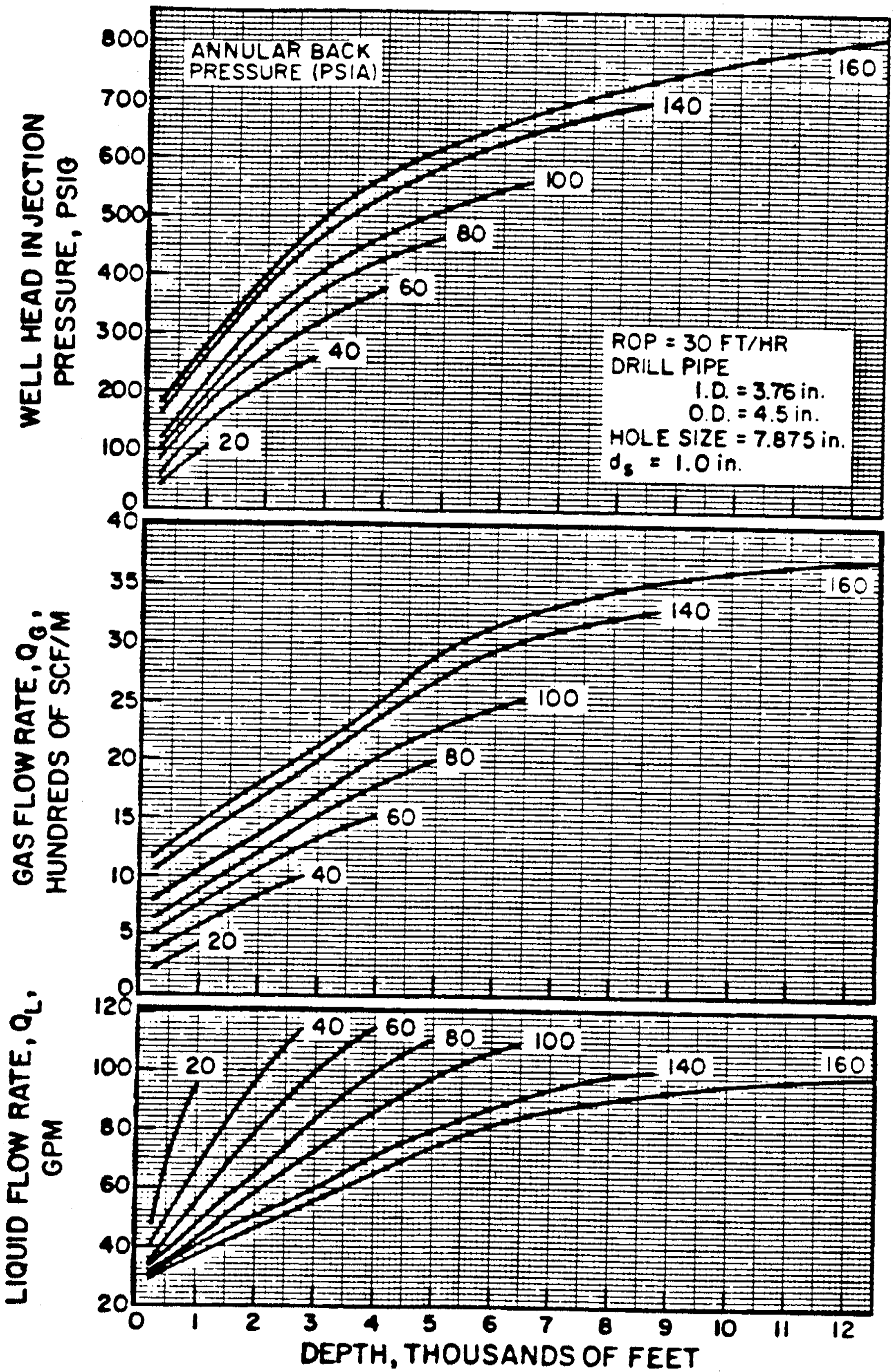

Figure B.5: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 30 ft/hr; Particle Size = 1.0 in.)

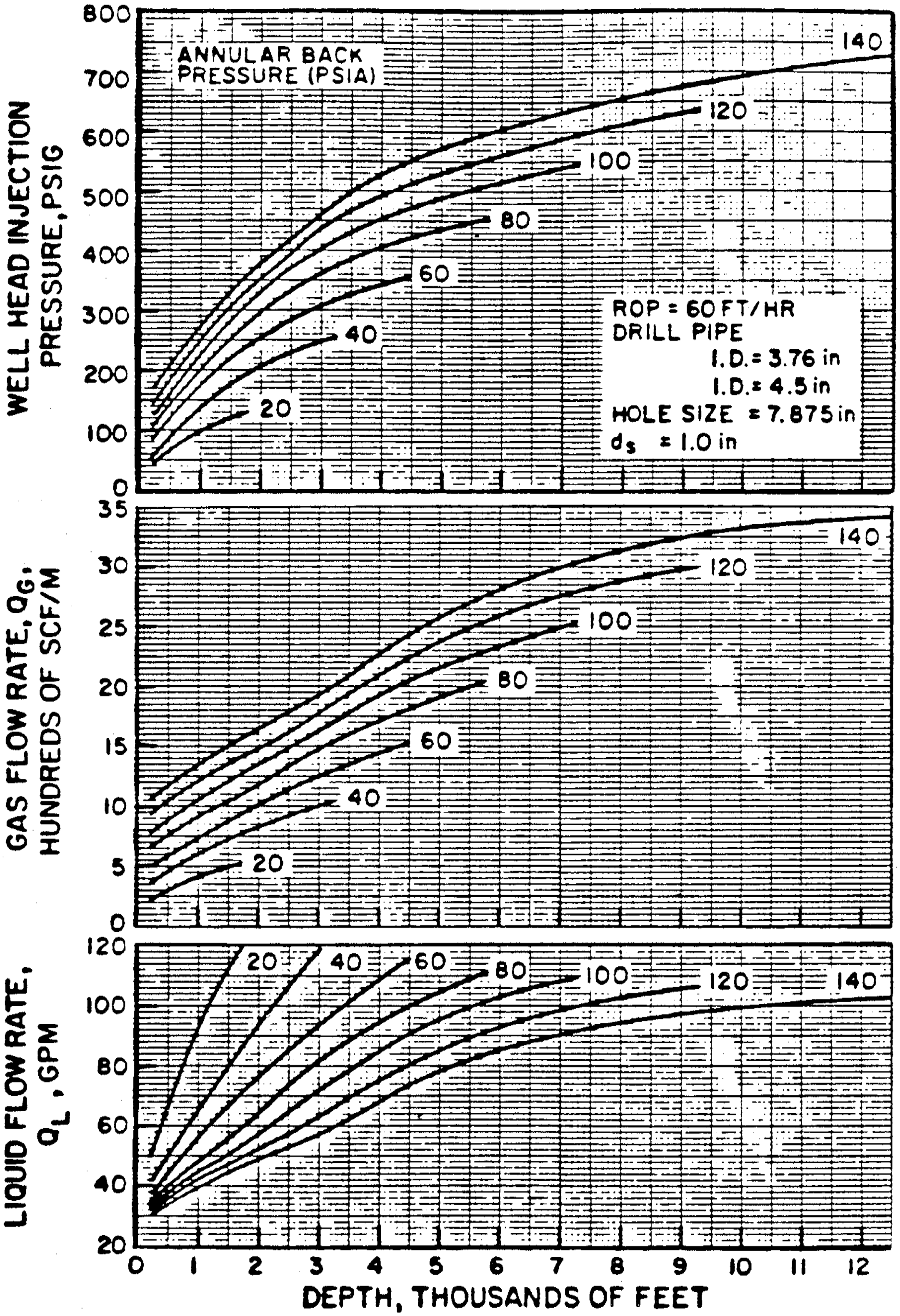

Figure B.6: Volumetric Requirements for 4.5 in. Drill Pipe in 7.875 in. Hole (Penetration Rate = 60 ft/hr; Particle Size = 1.0 in.)

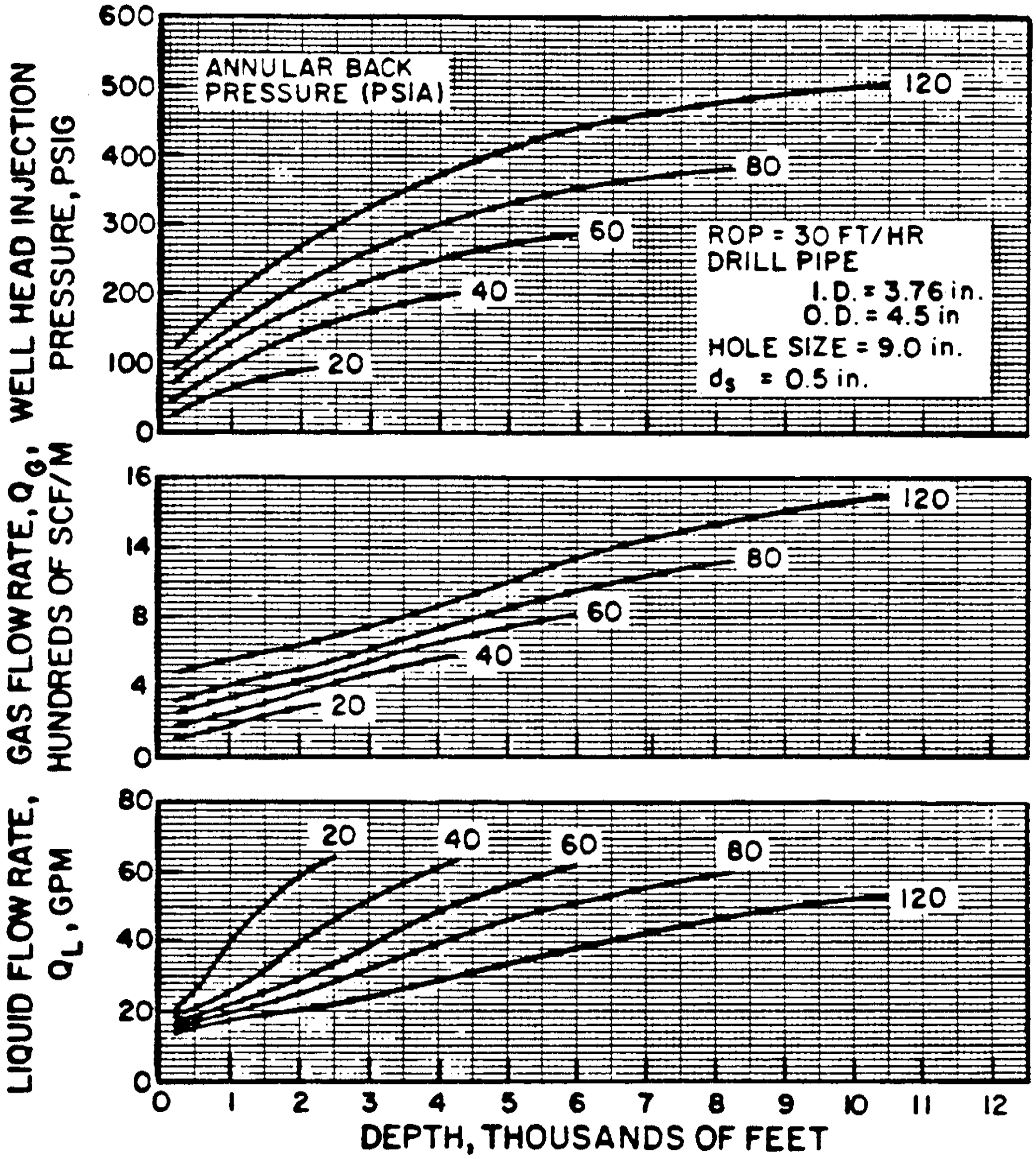

Figure B.7: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 30 ft/hr; Particle Size = 0.5 in.)

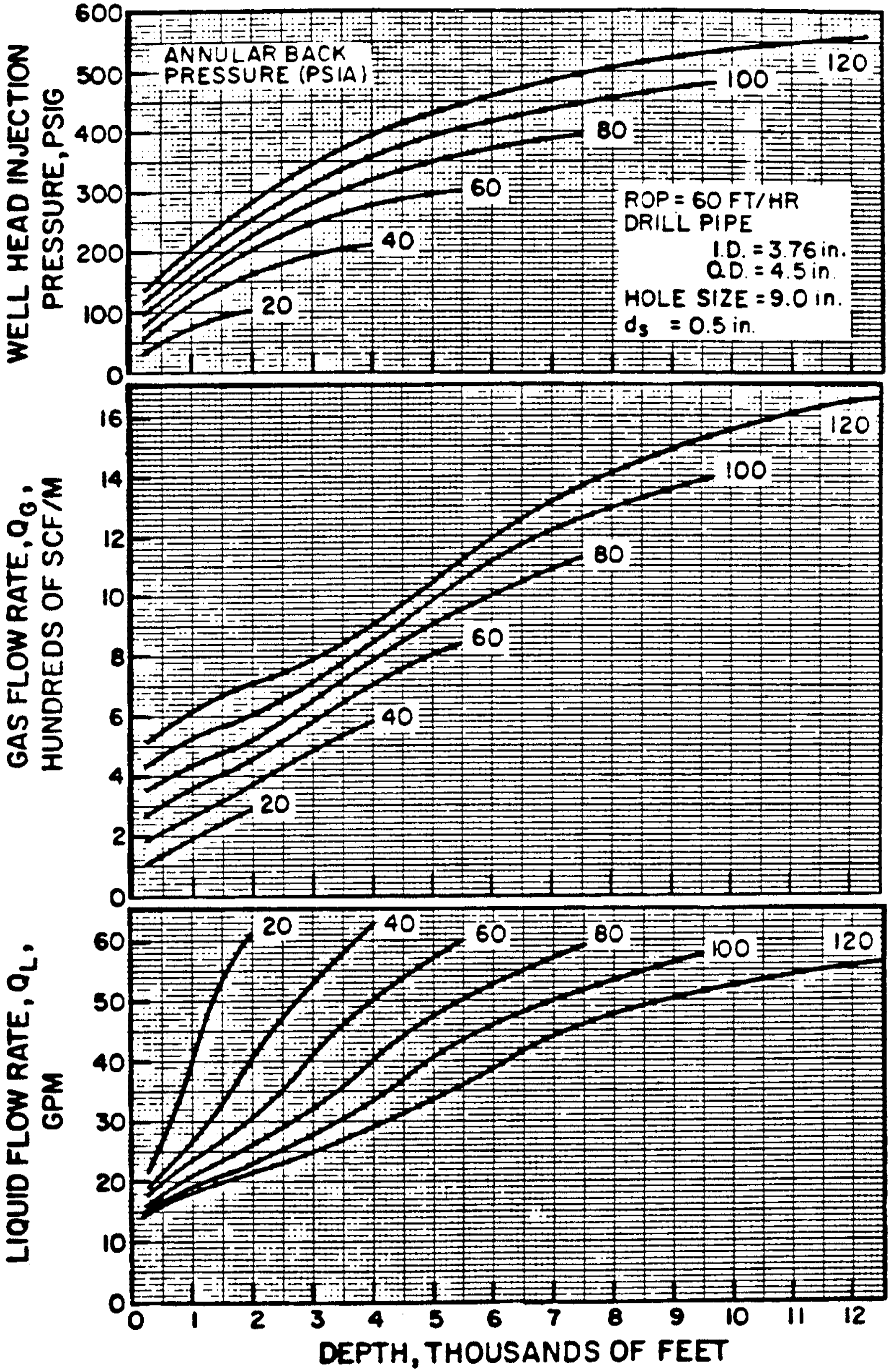

Figure B.8: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 60 ft/hr; Particle Size = 0.5 in.)

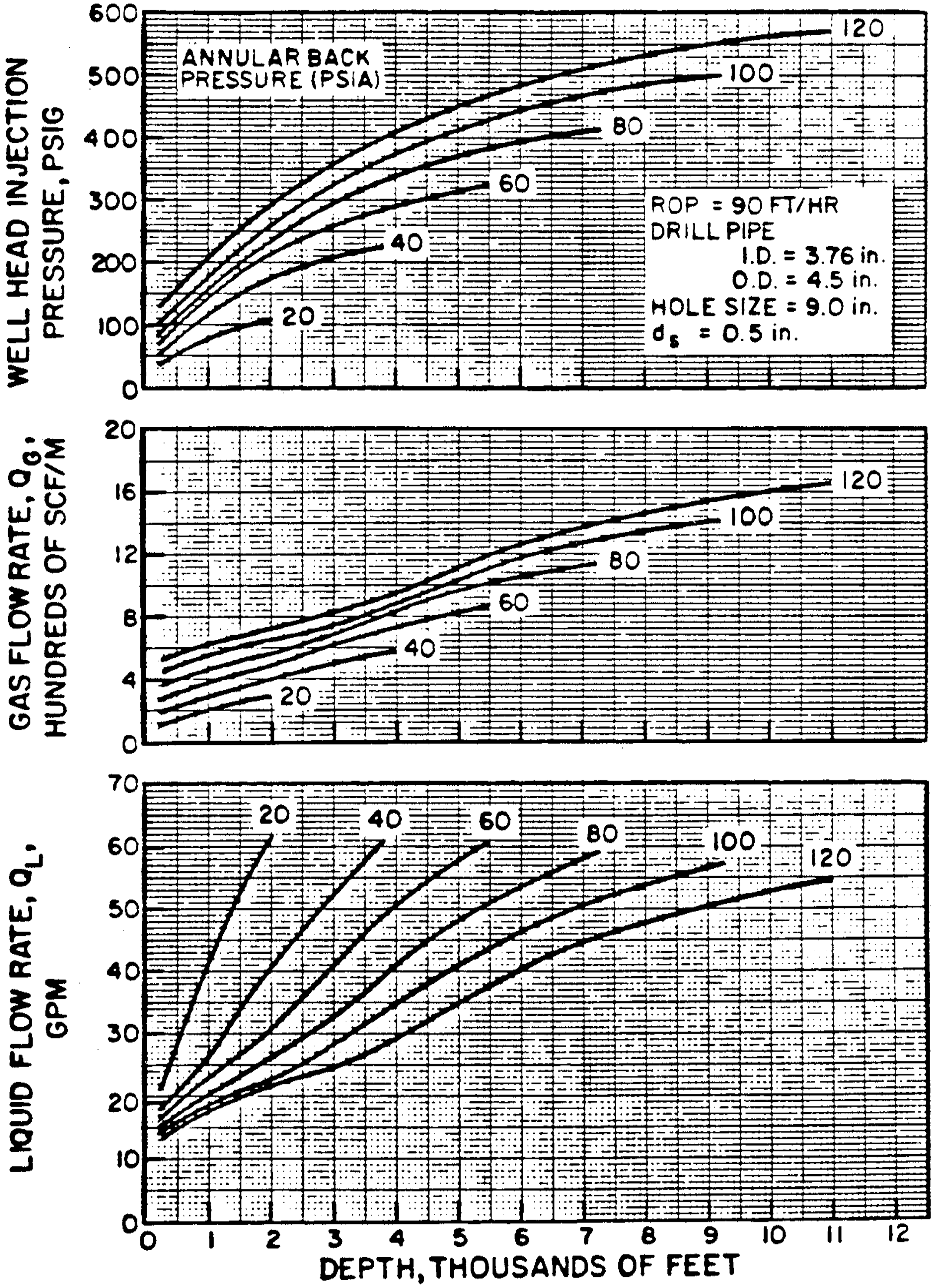

Figure B.9: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 90 ft/hr; Particle Size = 0.5 in.)

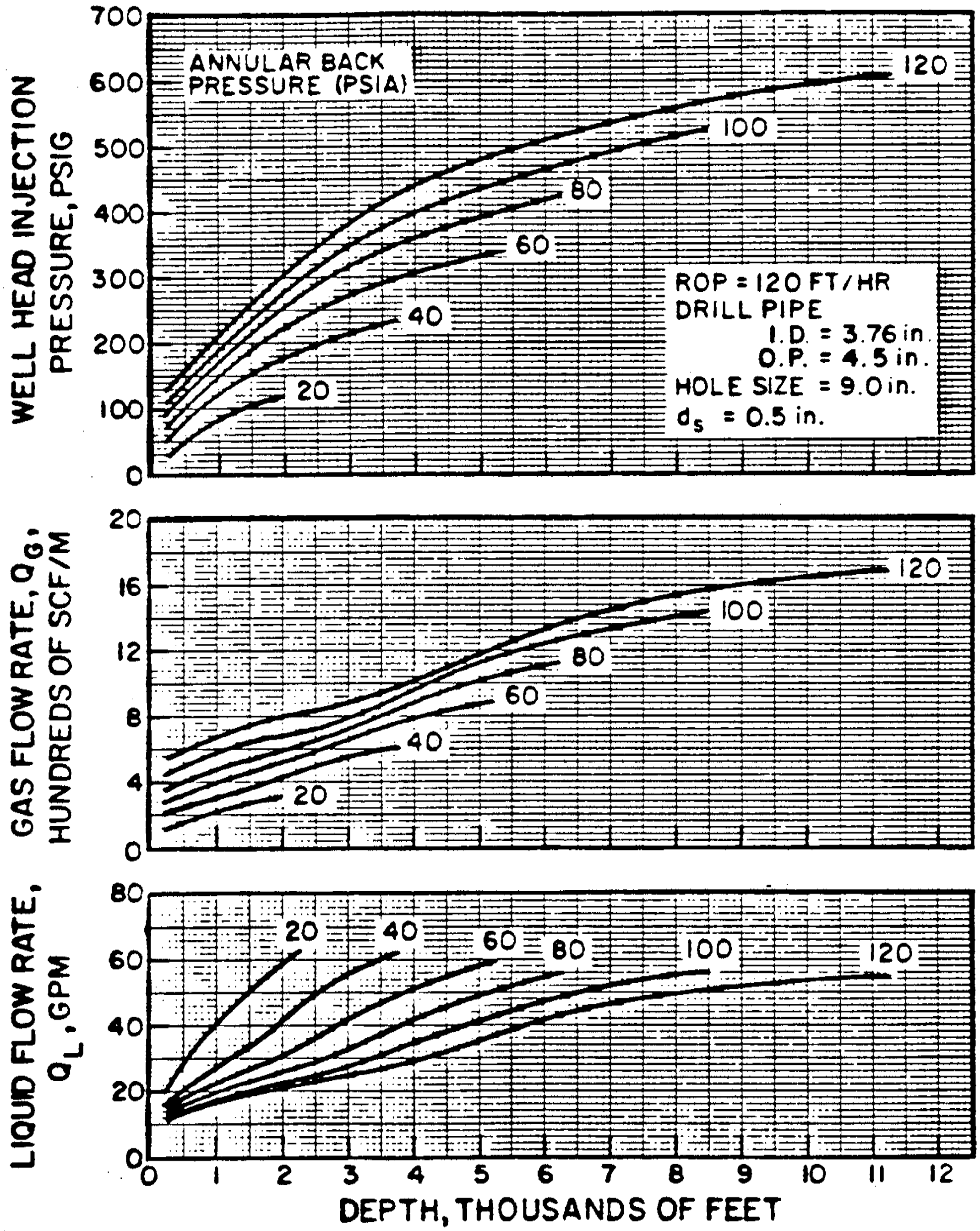

Figure B.10: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 120 ft/hr; Particle Size = 0.5 in.)

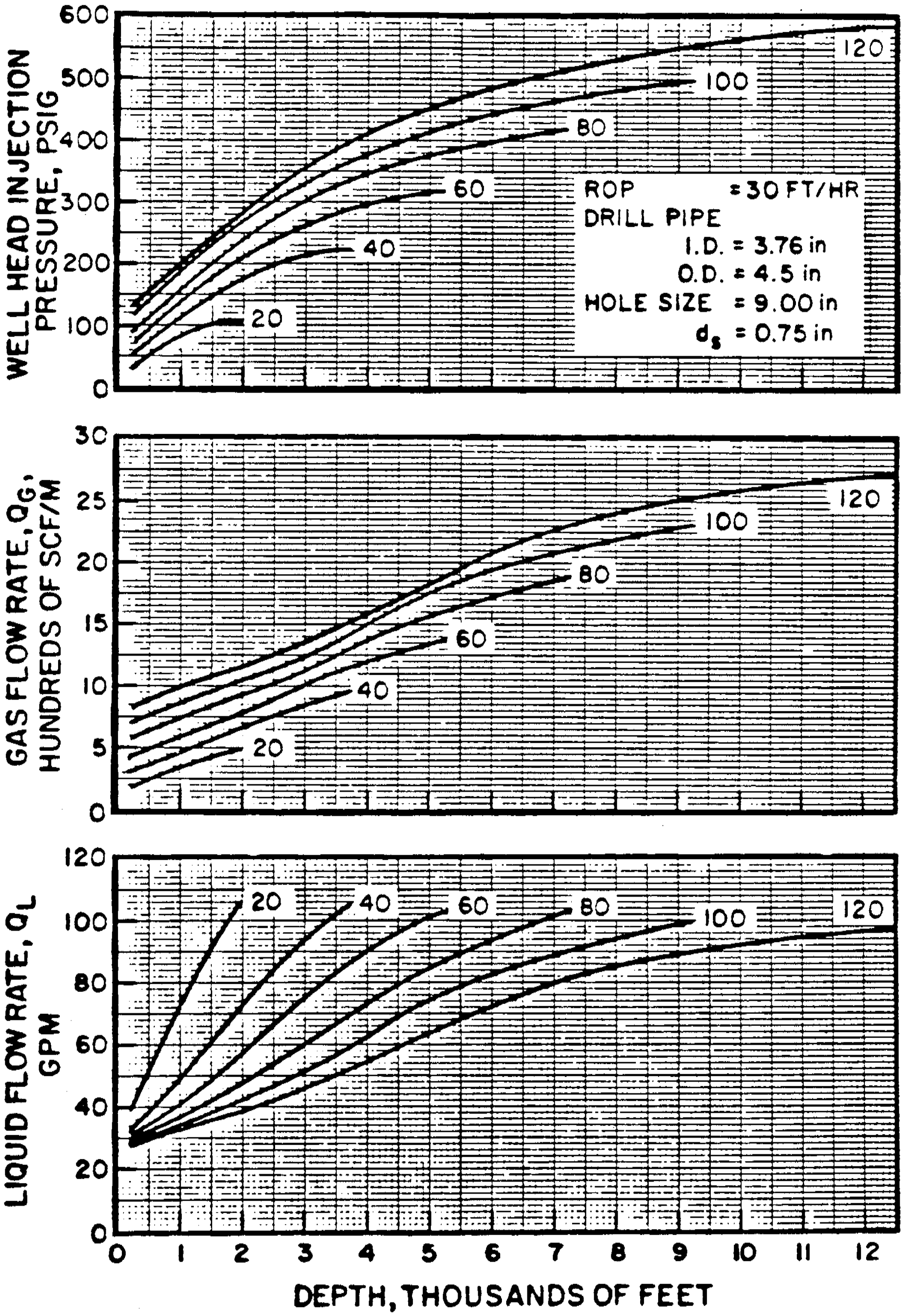

Figure B.11: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 30 ft/hr; Particle Size = 0.75 in.)

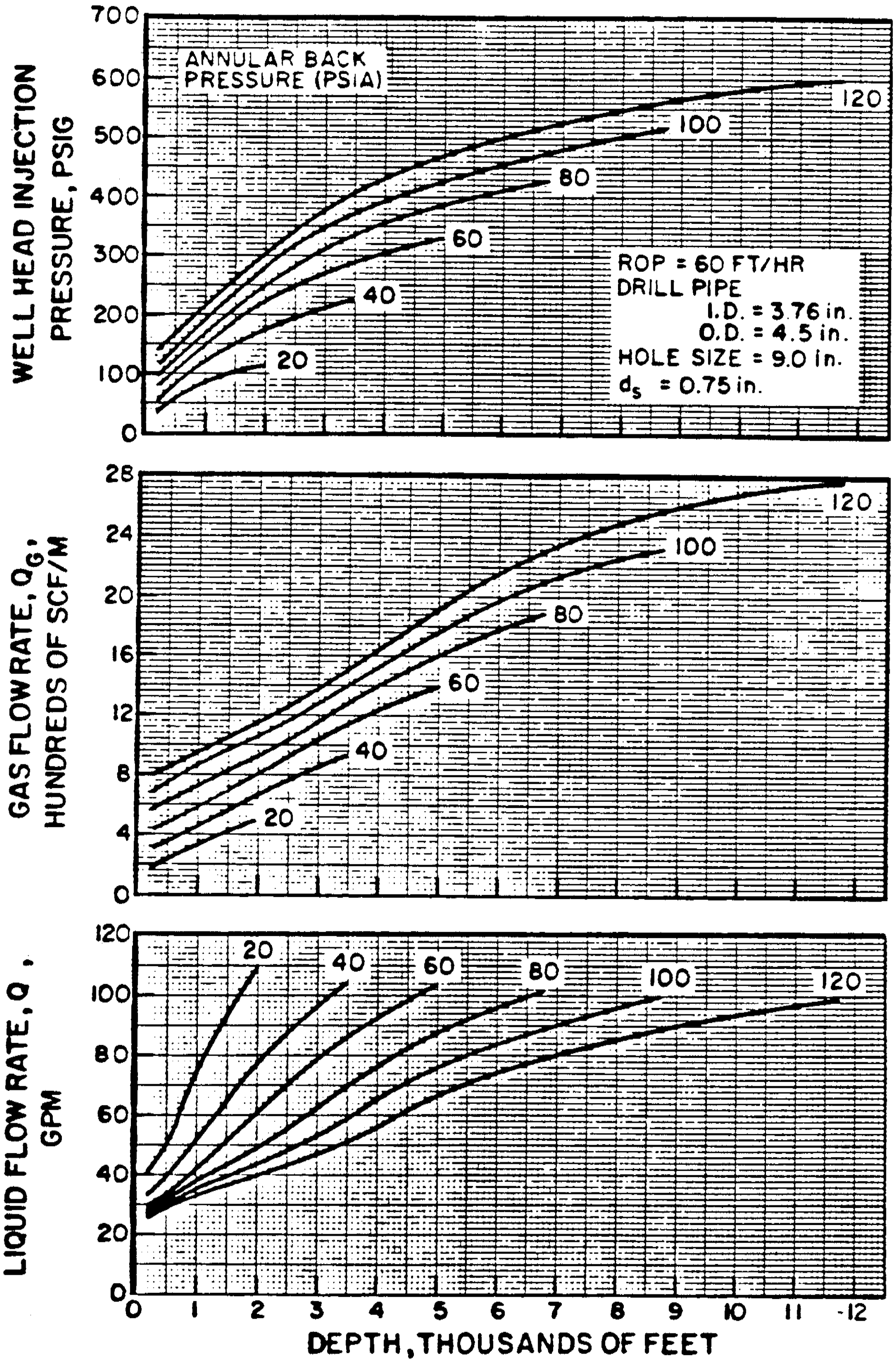

Figure B.12: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 60 ft/hr; Particle Size = 0.75 in.)

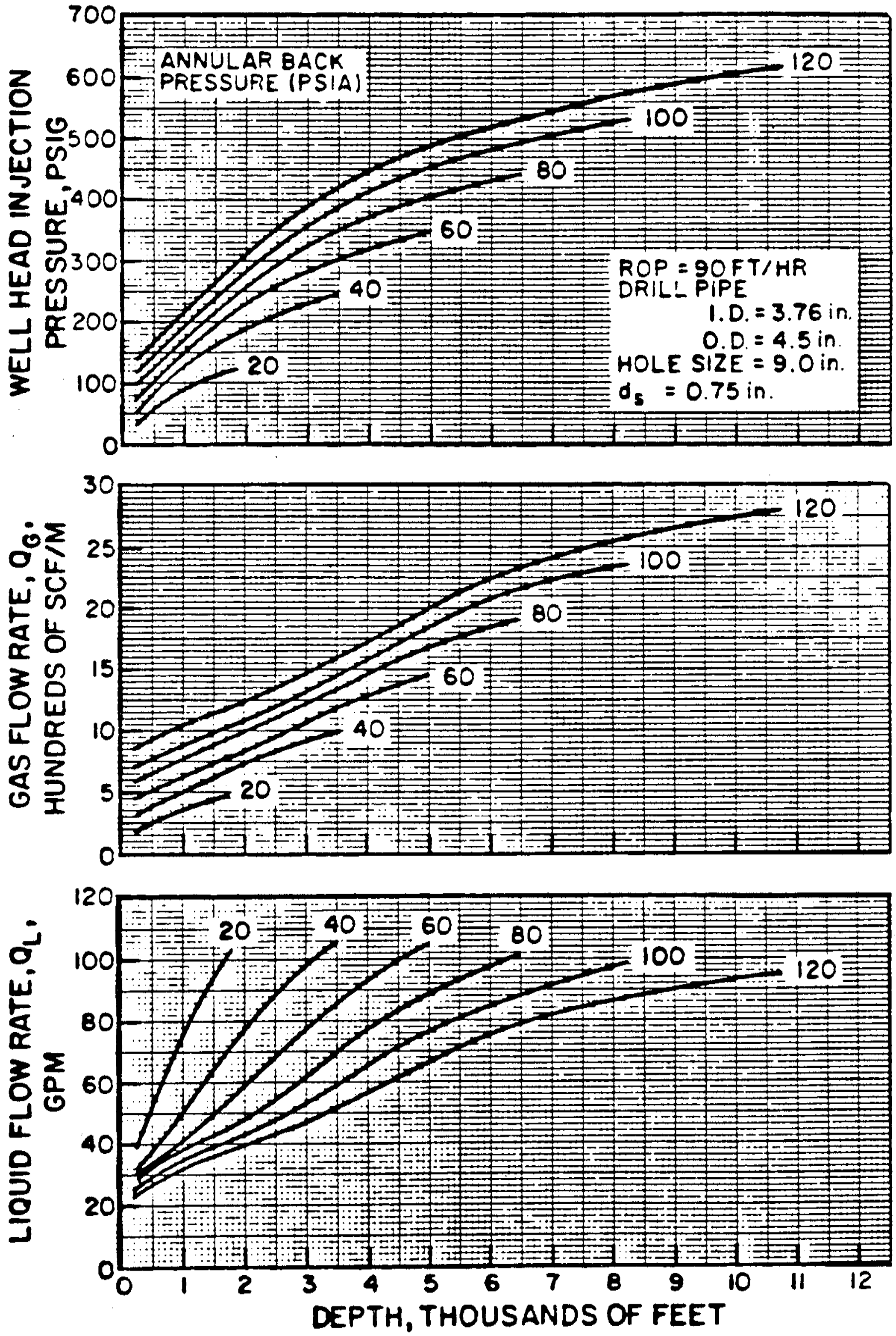

Figure B.13: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 90 ft/hr; Particle Size = 0.75 in.)

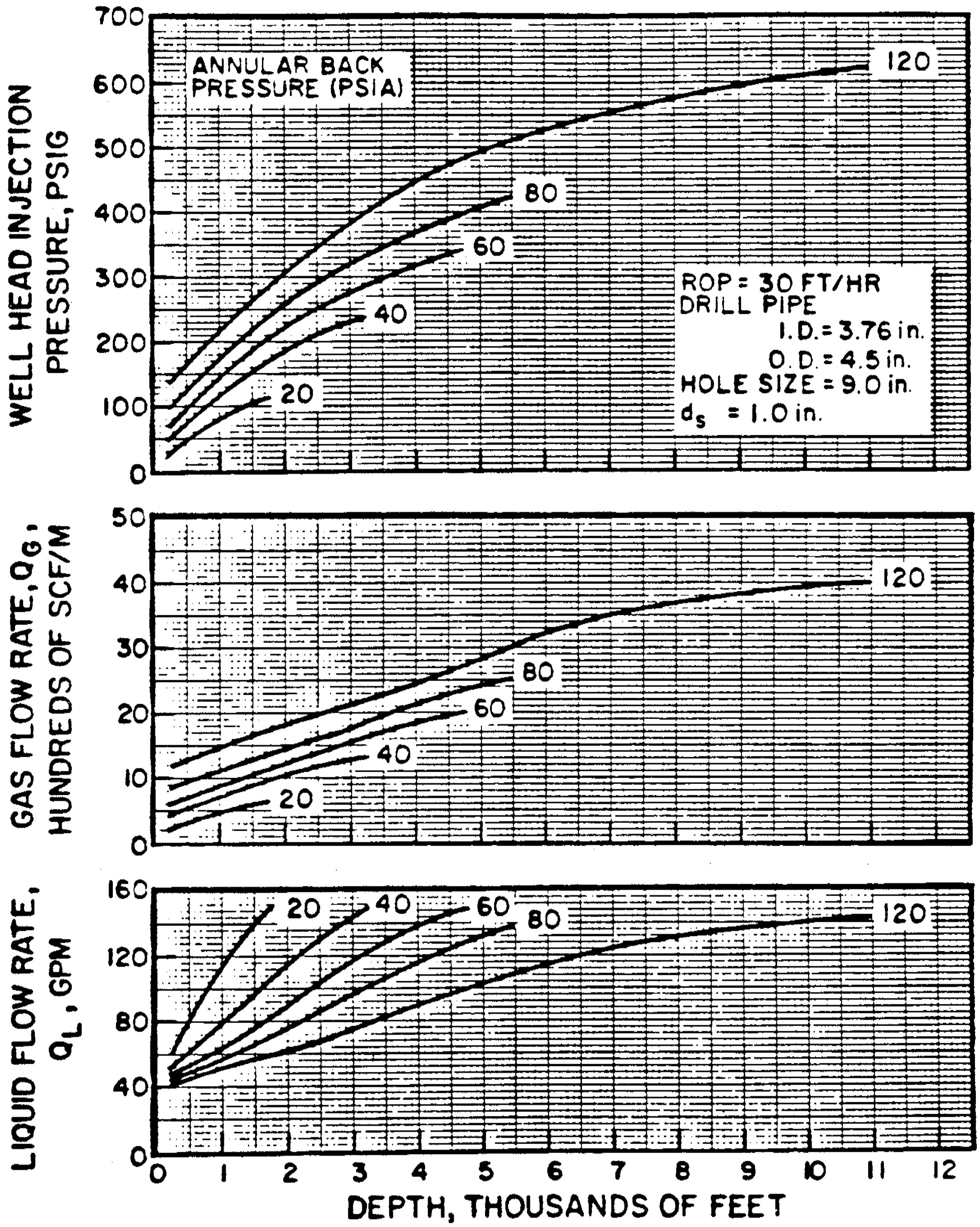

Figure B.14: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 30 ft/hr; Particle Size = 1.0 in.)

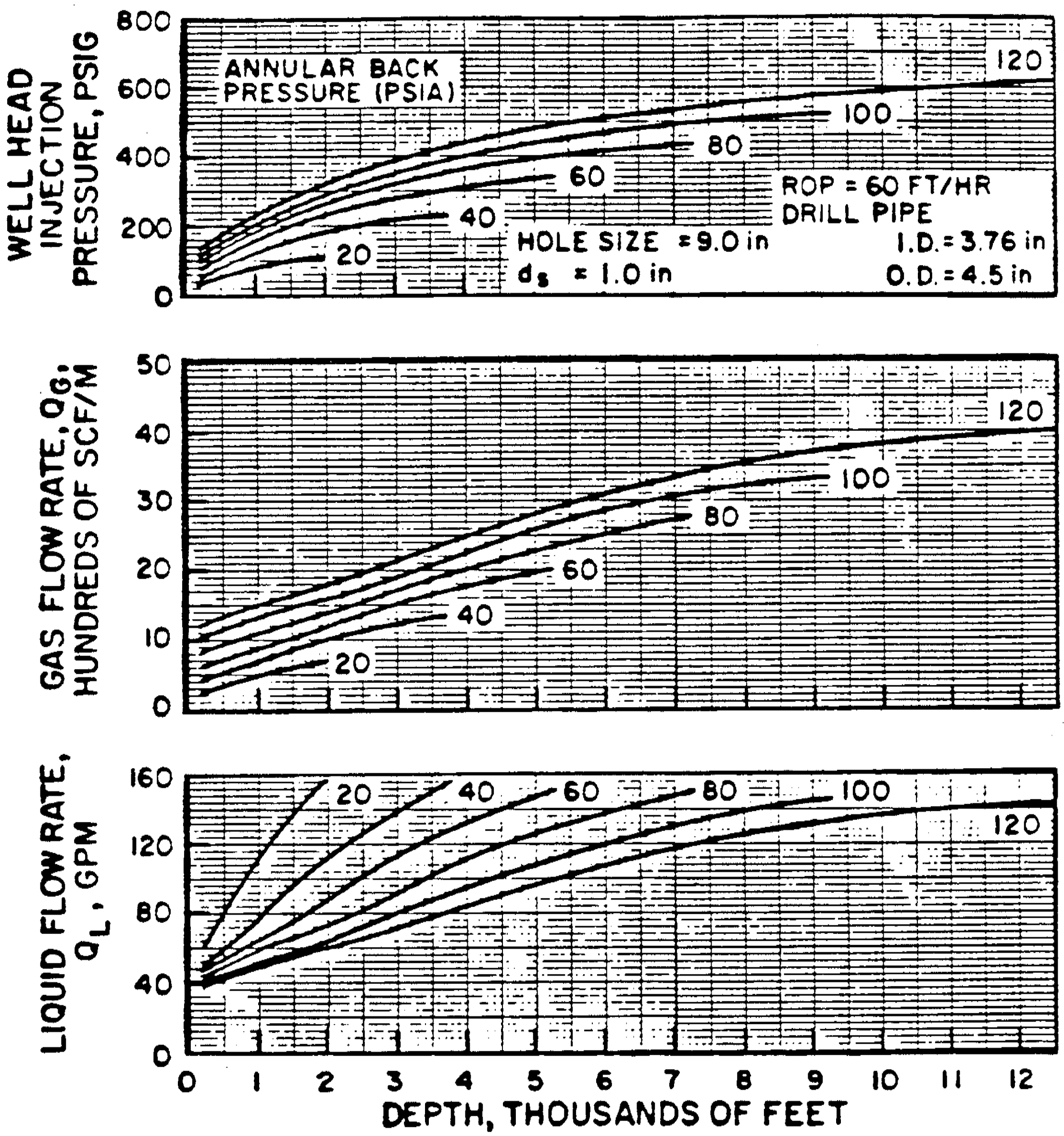

Figure B.15: Volumetric Requirements for 4.5 in. Drill Pipe in 9.0 in. Hole (Penetration Rate = 60 ft/hr; Particle Size = 1.0 in.)