UNITED STATES

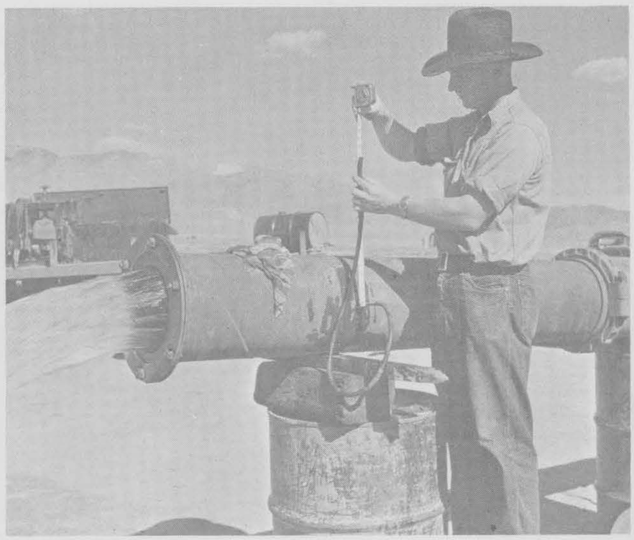
DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

FILTER PACK AND WELL SCREEN DESIGN

HYDROLOGIC LABORATORY

Denver, Colorado



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By A. I. Johnson

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ABSTRACT

Proper design of the filter (gravel) pack and well screen are very important in producing a fully successful well. Criteria developed from a review of literature on well design are used in an example to provide recommended design for the filter pack and well screen of a specific well.

INTRODUCTION

The full success of a well finished in sand and gravel formations requires not only the proper selection of screen or slot openings but also the proper development of a natural envelope, or the proper design of an artificially-placed envelope, of a sand or gravel filtering zone around the well casing. Ahrens (1957a) stated that the common usage is to refer to this zone as a "gravel pack," but also noted that the terminology is misleading because such packs may range in particle size from fine sand to coarse gravel--depending upon the gradation of the aquifer materials. Therefore, in this report, the term "filter pack" is used in place of "gravel pack."

The filter pack of uniform, relatively coarse, sand or gravel surrounding the well screen may be provided in two ways (E. E. Johnson, 1955). A naturally developed filter pack is produced by removing the fine sand and silt from the aquifer material, bringing these fines through the well screen openings by surging and bailing. An artificial filter pack is provided by drilling the hole larger than the well screen, centering the screen in the hole, and then filling the annular space around the screen with properly selected filter material consisting of carefully sized sand or gravel. The properly designed filter pack not only increases the effective diameter of the well but also insures a sand-free well.

For the naturally developed filter pack, the choosing of the correct size of screen openings permits development of the pack from the aquifer material at some distance outside the face of the screen (E. E. Johnson, 1955, 1963). For the artificially placed filter pack, choosing a properly graded sand or gravel that will retain part of the aquifer material, and corresponding screen or perforation openings that will retain most of the filter pack, will insure that the well will not continue to pump sand or gradually become plugged with fines filling the spaces in the screen or in the filter pack.

According to Johnson (E. E. Johnson, 1959), an artificial filter pack is required primarily when the aquifer is a very fine and uniform sand. In most other cases a naturally developed filter pack is preferred.

Much of the early well-design information was developed by trial and error procedures, resulting in a variety of rules-of-thumb. However, in more recent years, study under both field and laboratory conditions has resulted in the development of scientific criteria for the proper design of well screens and filter pack. Now it generally is known that optimum well design should start with an analysis and interpretation of the aquifer properties, including the particle-size distribution of the aquifer materials (E. E. Johnson, 1963).

THEORY OF DESIGN

To provide background for the filter pack and screen design of the recharge well, some of the pertinent literature is reviewed in the following paragraphs.

Design of Filter Pack

As early as 1921, Terzaghi (1951) used and patented in Austria a filter well to control seepage under a dam. His studies determined that the filter pack must be many times more permeable than the aquifer material, but the filter pack must not be coarse enough to allow the fine particles of the aquifer material to continue to wash through the pack. To make the filter pack approximately ten times as permeable as the aquifer material, Terzaghi concluded that the 15-percent size of the filter pack should be at least four times as large as the 15-percent size of the aquifer material. He also concluded that, to prevent the fine particles of the aquifer material from continuously washing through the filter pack, the 15-percent size of the filter pack should not be more than four times as large as the 85-percent size of the aquifer material.

Gumpertz (1941) made detailed studies of filter-pack design in connection with the flow of oil in oil wells. He found the effective size (D_{10}) of the filter pack should be 11 times as large as the effective size of the aquifer materials.

The U.S. Corps of Engineers (1941, 1942) did considerable research, both in the laboratory and field, on the proper design of filter packs and screens for relief wells. These studies concluded that the particle-size-distribution curves for filter pack and aquifer materials should be approximately parallel in order to minimize washing of the fine aquifer material into the filter pack. The filter pack design was found to depend upon the following criteria for filtering stability:

$$\frac{\text{15-percent finer size of filter pack}}{\text{85-percent finer size of finest aquifer material}} \leqq 4$$

and for maximum permeability:

$$\frac{\text{15-percent finer size of filter pack}}{\text{85-percent finer size of coarsest aquifer material}} \geqq 4.$$

More recently, laboratory studies by the Corps of Engineers (1948) determined that the following additional criteria were needed for greater stability of filter pack:

$$\frac{\text{15-percent finer size of filter pack}}{\text{15-percent finer size of coarsest aquifer materials}} < 20$$

and $$\frac{\text{50-percent finer size of filter pack}}{\text{50-percent finer size of aquifer materials}} < 25.$$

Bennison (1947) noted that optimum design of the filter pack depends upon a specified ratio between the effective size of the pack and of the aquifer material; beyond this ratio the pack will not "bridge" and below it the pack will reduce the yield of the well. He also pointed out that the uniformity coefficient of the filter pack is related somewhat to the uniformity coefficient of the aquifer material, but, in general, it should be 2 or less. The amount of bridging is affected by the angularity and shape of the particles as well as by the uniformity of size distribution. Bennison also noted that the filter pack should be placed in a minimum space of three inches, with a maximum thickness of 12 inches.

In 1950, Bertram found from laboratory studies that the 15-percent size of the filter pack should be approximately six times larger than the 85-percent size of the aquifer material if stable filtering conditions are to result. He also found that the limiting sizes were the same, regardless of whether the flow was upward or downward, within a wide range of hydraulic gradients.

Smith (1954) found from field studies in Illinois that the size ratio of the 50-percent size of the filter pack to the 50-percent size of aquifer material should be 4 to 5. Wells with smaller or larger ratios had less efficiency.

E. E. Johnson (1955, 1963) found that a filter pack with a thickness of only a fraction of an inch would successfully retain the particles of the aquifer materials regardless of the velocity of the water. The thicker the filter pack, the more difficult it becomes to insure complete removal of the drilling-mud cake from the aquifer during development of the well. Thus, Johnson pointed out that a larger effective diameter of well may be somewhat beneficial, but only if the well-development work can be depended upon to effectively undo any damage to the permeability of the aquifer resulting from the sealing effects of the drilling mud. Because it is impractical to place in a well a filter pack with a thickness of a fraction of an inch and expect to have it completely surround the screen, a thickness of three inches is the minimum that is considered practical for installation in the field. A filter-pack thickness of 8 to 9 inches is considered the maximum that will insure that the drill hole may be thoroughly cleaned through the development process and that the formation will thus be restored to at least its original permeability.

The artificially placed filter pack has been designed (E. E. Johnson, 1963) so it has a uniformity coefficient of 2.5 or less, with a 30-percent retained size about 4 to 6 times as large as the 30-percent retained size of the aquifer material. The factor 4 is used if the aquifer is fine and uniform in particle-size and 6 is used if it is coarser and nonuniform. If a uniform pack material is used, there is less hydraulic segregation of the various particle sizes while the filter pack material is settling down through the annular space around the well casing.

According to Johnson (E. E. Johnson, 1963) the filter pack materials ideally should be clean, with well-rounded particles that are smooth and uniform. These characteristics tend to increase the porosity, and hence the permeability, of the filter pack. Johnson also notes that the pack material should consist mainly of siliceous rather than calcareous particles, common specifications requiring that not more than 5 percent of the pack will consist of calcareous particles. Pack materials containing shale, anhydrite, or gypsum, also are not desirable.

Ahrens (1957b) stated that the U.S. Bureau of Reclamation found that there was negligible settlement of filter pack during pumping operations if a uniform particle-size pack was used. The Bureau of Reclamation concluded that the ratio of the 50-percent size of the filter pack to the 50-percent size of the aquifer material should be between 5 and 10 for a uniform filter pack. (Also see Smith, 1954, and Bureau of Reclamation, 1960, p. 322-325.) To avoid trouble in placing filter-pack materials, Ahrens indicated that the packs should not contain particles greater than 13 mm (one-half in.) in diameter.

Two reeent British papers (Stow, 1962; Swales, 1963) have corroborated some phases of the studies previously reviewed in this report. Stow concluded that the 50-percent size of the filter pack should be 5 times the 50-percent size of the aquifer material. Swales emphasized that the filter pack should have a uniformity coefficient near to one to prevent segregation of the pack during placement.

Design of Well Screen

As pointed out by E. E. Johnson (1938), one of the most important items in the successful design of a well finished with a natural filter pack is the proper selection of slot opening in relation to the sizes of aquifer materials or, in the case of an artificially placed filter pack, the proper selection of slot opening in relation to the size of filter-pack materials. In the latter case, an opening is selected that will retain the filter pack and, in turn, filter pack is selected that will retain the aquifer material. In either type of well construction, the well screen should be looked upon as a type of "stabilizer," rather than as a "strainer."

Johnson (E. E. Johnson, 1959) noted further that it was generally believed in earlier years that a properly designed screen excluded the greatest possible percentage of the aquifer material. Over the years, larger openings have been found to be more efficient and more recent practice now considers that as much as 60 percent, and in a few cases even more, of the aquifer material may pass through the selected screen or slot openings.

The Corps of Engineers' (1941, 1942) studies discussed earlier also reached conclusions regarding well-screen design. For screens installed without filter packs, they found that the screen diameter had relatively little effect on the efficiency of the well system, but that the perforated section should have at least 100 perforations totaling an open area of 3 sq in per ft of section for most efficient operations. For screens installed with filter packs, the perforated section should have at least 25 perforations totaling an open area of 1 sq in per ft of section. Washing in of sand after initial pumping was prevented if the screen or perforated openings were designed according to the following criteria:

$$\frac{\text{85-percent finer size of filter pack or aquifer material}}{\text{Screen opening or perforated opening}} \geqq 1.$$

Ahrens (1957b) noted that the screen opening should be about one-half the diameter of the 85-percent size and that, for a well finished in several different aquifer zones, the screen opening, and the filter pack as well, should be designed to control the aquifer with the finest material. He pointed out that this procedure is permissible if the 15- and 50-percent sizes of the material in the coarsest aquifer are no more than 4 times the same sizes of the material in the finest aquifer. If the spread of particle-size is greater than about 4 times, then the screen or perforation openings and filter pack must be designed for the individual aquifers.

In the naturally developed well, it has been pointed out (E. E. Johnson, 1963) that the openings of the well screens have been chosen so as to retain about 40 percent of the aquifer material and thus let 60 percent pass through the openings during the development process. The screen opening for the artificially placed filter pack is designed so that it will retain much of the aquifer material, and the screen opening then is selected to retain the filter pack. E. E. Johnson (1963) recommended an opening that will retain 90 percent of the pack.

Example of Design

Considerable time and effort are required to complete a screened well correctly, whether it be a naturally developed or an artificially placed filter pack, but proper development will improve almost any type of well. If the relationships referred to in the previous discussion are disregarded in the construction of the well, fine sand may pass into the voids of the filter pack and thus decrease the yield of the well. Also, fine sand may continue to pass through the filter pack and screen into the well, resulting in considerable damage to the pumping equipment or even in collapse of the well. Thus, it is very important that a well be designed by use of the best possible criteria known at present.

The data for a recharge well, as contained in a report by Johnson, Moston, and Versaw (1965), is used in the following example for design of filter pack and well screen.

Calculation of Design Criteria

The laboratory and field studies by the U.S. Corps of Engineers (1941, 1942, 1948) were quite thorough but their design criteria were based primarily upon the requirements for pressure relief wells in which continuous operation and maximum influx of sand were not primary concerns. A more conservative design must be used for the usual water wells because they should not continue to pump sand and at the same time should have the highest possible specific capacity. Therefore, criteria established by the Corps of Engineers, as well as those established by E. E. Johnson (1963), will be used in designing a filter pack and a well screen for an artificial-recharge well.

The Corps of Engineers' criteria for filter-pack and well-screen design are as follows:

$$D_{15} \text{ filter pack} \geqq 4(D_{15} \text{ aquifer}),$$
$$< 20(D_{15} \text{ aquifer}),$$
$$D_{50} \text{ filter pack} < 25(D_{50} \text{ aquifer}),$$
$$\text{Screen opening} \leqq D_{85} \text{ aquifer};$$

where

D_{15} = diameter of particle-size distribution curve for which 15 percent are finer,

D_{50} = diameter of particle-size distribution curve for which 50 percent are finer,

D_{85} = diameter of particle-size distribution curve for which 85 percent are finer.

Criteria established by E. E. Johnson (1963) and used for the present filter-pack and well-screen design are as follows:

$$D_{30} \text{ filter pack} \geqq 4(D_{30} \text{ aquifer}),$$
$$< 6(D_{30} \text{ aquifer}),$$
$$\text{Screen opening} \leqq D_{50-70} \text{ aquifer},$$
$$\leqq D_{10} \text{ filter pack.}$$

The data determined by these design criteria are summarized in table 1 for all aquifer samples obtained from the test hole which was an exploratory hole for a recharge well. These design data then were used to derive the particle-size distribution graphs (fig. 1) proposed for an artificial filter pack for the recharge well. The design curves based on Corps' criteria were derived by drawing curves with low uniformity coefficients through the filter-pack design data points, with primary use of the median diameter (D_{50}) criteria. The design curves based on E. E. Johnson's (1963) criteria were derived by drawing curves of low uniformity coefficients through the design point at the D_{30} size.

Figure 1 shows that the aquifer materials fall into two general groups, those from depths of 65 to 115 feet (represented by samples 58ARK54-63) and those from depths of 115 to 127.5 feet (represented by samples 58ARK64-67). Thus, the filter-pack-design curves also fall into 2 general groups and are represented by the 2 patterned bands in figure 1. Any pack having a particle-size distribution within its appropriate band in figure 1 will be satisfactory.

Table 1.--Data for proposed design of well screen and filter pack for a recharge well in Arkansas

Laboratory sample number	Aquifer				Corps of Engineers (1948) design data				E. E. Johnson (1963) design data				
					Filter pack		Screen design		Filter pack	Screen design			
	D_{15} size (mm)	D_{30} size (mm)	D_{50} size (mm)	D_{85} size (mm)	D_{15} size limits	Maximum D_{50} size (mm)	Screen opening without filter pack		Average D_{10} size (mm)	Screen opening with filter pack		Screen opening without filter pack	
							(in.)	Slot no.		(in.)	Slot no.	(in.)	Slot no.
58ARK54	0.10	0.22	0.29	0.37	0.4-2.0	7.2	0.014	14	0.075	0.030	30	0.012	12
55	.08	.15	.23	.36	.3-1.5	5.7	.014	14	.075	.030	30	.009	8
56	.10	.16	.22	.34	.4-2.0	5.5	.013	14	.075	.030	30	.009	8
57	.10	.17	.23	.32	.4-2.0	5.7	.012	12	.075	.030	30	.009	8
58	.13	.22	.30	.43	.5-2.5	7.5	.017	16	.075	.030	30	.012	12
59	.12	.20	.28	.44	.5-2.5	7.0	.017	16	.075	.030	30	.011	10
60	.20	.28	.33	.42	.8-4.0	8.2	.016	16	.075	.030	30	.013	12
61	.19	.30	.34	.54	.8-4.0	8.5	.021	20	.075	.030	30	.014	14
62	.21	.27	.31	.44	.8-4.0	6.5	.017	16	.075	.030	30	.012	12
63	.21	.24	.28	.36	.8-4.0	7.0	.014	14	.075	.030	30	.011	10
64	.27	.42	.55	1.50	1.1-5.5	14.5	.059	60	1.60	.064	60	.022	22
65	.29	.40	.51	1.50	1.2-6.0	12.7	.059	60	1.60	.064	60	.020	20
66	.28	.33	.40	.62	1.1-5.5	10.0	.024	20	1.60	.064	60	.016	16
67	.27	.33	.37	.54	1.1-5.5	9.2	.021	20	1.60	.064	60	.015	14

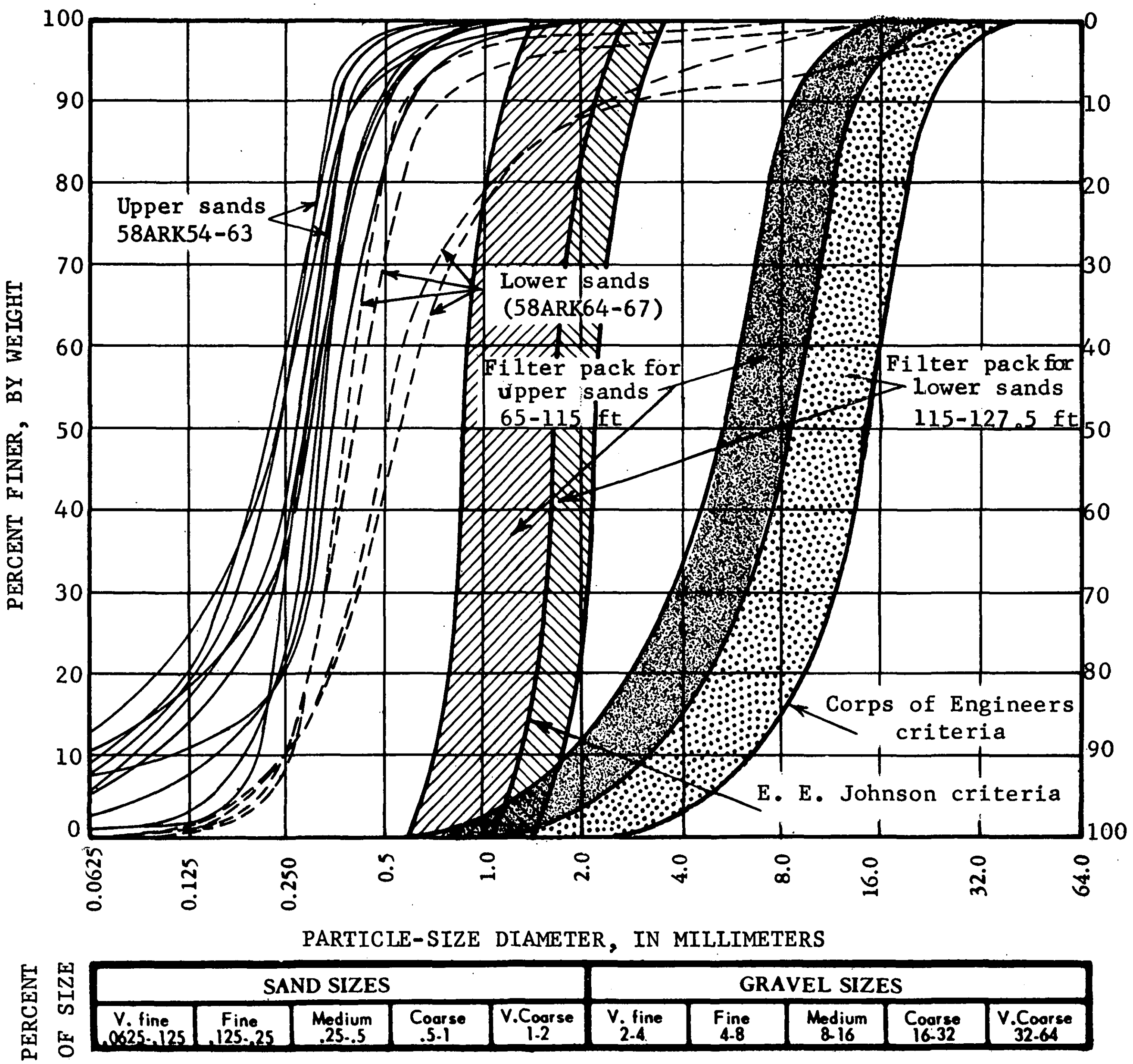

Figure I.--Graph showing filter-pack design curves as proposed for a recharge well.

Recommendations for Design

Optimum design of the recharge well would require placement of a pack having a distribution similar to the right-hand pattern at the depths below 115 feet and similar to the left-hand pattern at depths above 115 feet. However, it is not practical to place two different packs for most wells, so a pack designed for the aquifer with the finest material should be used if both fine and coarse aquifers are screened.

Figure 1 shows that a pack similar to the distribution of the left-hand part of the design filter pack, using either the Corps of Engineers' (1948) or E. E. Johnson's (1963) criteria, should be used if both fine and coarse aquifers are screened. However, if only the coarse aquifer is to be screened, then the filter-pack design should be based on the design curves for that particular material; for example, the right-hand part of the design curves in figure 1.

Because E. E. Johnson's (1963) criteria were established more specifically for water-supply wells rather than for pressure-relief wells, those criteria will be used for determining the design filter pack (left-hand curves, fig. 1). Only the coarse aquifer (below 115 ft) should be screened, so the filter pack should have a distribution similar to the right-hand part of the set of curves.

An artificially placed filter pack is recommended because of the small screen openings that would be required for natural development. The screen also is designed according to criteria established by E. E. Johnson (1963); a screen with openings of 1.6 mm (0.064 in. or slot No. 60) is recommended.

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