AN ABSTRACT OF THE THESIS OF

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(Name) (Degree)
in CIVIL ENGINEERING presented on (Major) (Date)

Title: SAND PUMPING EFFICIENCY OF A WATER EJECTOR

APPARATUS

Abstract approved:

Redacted for Privacy

The purpose of this investigation is to study the effect of the solid transport capacity in pumping operation. A special type of jet apparatus was investigated which emits a water jet downward counter current to delivery flow, from inside of the suction pipe toward sediment to be excavated. Two sizes of jet pipe were considered; each was tested at three different positions for a centrifugal delivery pump operated in its economic range of operation.

This jet pipe discharge was confirmed to increase sand transport capacity of the centrifugal delivery pump as the jet mouth was in the position close to the annular suction mouth. At this position, the sand transport capacity of the centrifugal delivery pump increased as the jet discharge increased. When the jet mouth was positioned above the area close to the suction mouth, the sand transport capacity of the centrifugal delivery pump decreased. As the jet mouth was extended
below the area close to the suction mouth, the sand transport capacity of the centrifugal delivery pump was nearly equal in either case of pumping with or without the jet water in operation.
Sand Pumping Efficiency of a Water Ejector Apparatus

by

Suvat Saguanwongse

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the degree of

Master of Science

June 1968
APPROVED:

Redacted for Privacy

Associate Professor of Civil Engineering

in charge of major

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Date thesis is presented ____________________________
May 7, 1978

Typed by Clover Redfern for Suvat Saguanwongse
ACKNOWLEDGMENTS

The author wishes to express sincere appreciation and gratitude to his major professor Dr. Larry S. Slotta for his guidance, understanding, patience and personal encouragement throughout his graduate work, during the course of this study and in preparation of this thesis.

Sincere appreciation is also extended to Dr. Peter C. Klingeman and Dr. Robert W. Filmer for their valuable suggestions and warm friendship.

The author wishes to thank his wife and friends who helped during the research period.

He is also deeply grateful to his parents for encouragement and financial support throughout his period of study at Oregon State University.

In addition, the author is grateful to the National Energy Authority and the Government of Thailand for granting leave of absence.
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SAND PUMPING EFFICIENCY OF A WATER EJECTOR APPARATUS

INTRODUCTION

General

The hydraulic transport of solid materials in pipes is of considerable engineering interest. It is common practice to transport solid materials by mixing with a liquid and pumping the resultant slurry through a pipe line (Durand, 1953; Zandi and Govatos, 1967).

The centrifugal pump, by its simple construction offers economical means for pumping solid-fluid mixtures. Its use is in evidence in dredging (Simon, 1920; U. S. Army Corps of Engineers, 1954), mining and industrial engineering (Colorado School of Mines Research Foundation, 1963; Nardi, 1959). For most fluid-solid applications, centrifugal pump selection usually is limited to single stage, slow speed pumps in order that maintenance may be minimized. Many makes of solid handling pumps are available in either open or closed impeller design. Closed impeller pumps are usually used for both coarse and fine slurries. Open impeller pumps are usually used for fine slurries under low head conditions and are not as efficient as closed impeller pumps. Most solid handling pumps are necessarily constructed of abrasive resistant materials.
Past Investigations of Pumping Solid-Fluid Mixtures

Past investigations of pumping solid-fluid mixtures are somewhat limited, and are next reviewed.

Centrifugal Pumping of Sand

The investigation by O'Brien and Folsom (1937) established that pump characteristics are different for solid-fluid mixtures than for water alone. The investigation by Fairbank (1940) dealt with the characteristics of a centrifugal pump of known dimensions while pumping in suspension material of various known sizes and concentrations. Fairbank states the following observationally based conclusions.

1. At a given capacity the head developed by a centrifugal pump, handling material in suspension, is in general less than that developed for water alone.

2. The drop in the constant speed head capacity characteristics varies not only as the concentration but also as the particles size of the material in suspension.

3. The fall velocity of the suspended material is the most important property in predicting the effect of the material on the pump performance.

4. The effect on the pump characteristics of fine particles in suspension such as colloids, is of a different nature than that of a true suspension.

5. The power input to a centrifugal pump varies directly with the apparent specific gravity of suspension being pumped.
6. The capacity of the maximum efficiency of centrifugal pump remains constant for all concentrations and sizes of suspended material.

7. The ordinary affinity relations of centrifugal pumps are valid within small ranges of speed when pumping material in suspension.

Jet Ejector Pumping of Sand

Frazier (1967) reported three basic forms of the jet pumps as shown in Figure 1. Figure 1a shows the centrally oriented nozzle with the dredge material entering at the periphery of suction annular pipe. Figure 1b shows another form which introduces the jet water through an annular ring with the dredge mixture entering centrally. The third basic form is a ring of nozzles around the periphery of the suction pipe as shown in Figure 1c.

Jet apparatus studies by Iwata and Fujii (1965) on a water ejector type similar to that sketched in Figure 1a confirmed increased sand transport capacity of a dredging pump by mixing sand around the jet nozzle, forwarding it into the pump suction mouth and by increasing the pressure within the suction mouth.

Purpose of the Present Study

Pumping solid-fluid mixtures, by using a jet apparatus which ejects a water jet toward the sediment field from within the suction
pipe, has been successfully used by industry for several years (Den-nen and Wilson, 1949). However no known documentation exists that characteristically describes the pumping of solid-fluid mixtures using this special type of the jet. The purpose of this investigation is to study the effect of solid transport capacity in pumping operations using a jet apparatus as shown in Figure 2 as the agitator.

Figure 1. Three basic forms of jet pumps.
Figure 2. Sketch of jet ejector and suction tank.
EJECTOR PERFORMANCE PREDICTION

At the present time there is no general accepted method which is capable of predicting quantitatively the performance of pumping solid-fluid mixtures using the jet apparatus as the agitator as shown in Figure 2. Dimensional analysis is used in the above pumping operation for the prediction of the sand transport capacity. In the case of pumping solid-fluid mixtures using the jet apparatus as the agitator, the significant physical quantities expected to affect the sand transport capacity $Q_s$ are

\[
\begin{align*}
Q_w &= \text{water capacity (volume per unit time)} \ L^3/T \\
q_j &= \text{jet capacity (volume per unit time)} \ L^3/T \\
D &= \text{diameter of suction pipe (length)} \ L \\
h_j &= \text{height of jet referring to suction mouth (length)} \ L \\
d_j &= \text{diameter of jet pipe (length)} \ L \\
\rho_s &= \text{density of solid (mass per unit volume)} \ M/L^3 \\
\rho_w &= \text{liquid density (mass per unit volume)} \ M/L^3
\end{align*}
\]

Using dimensional analysis, the original eight variables can be given in terms of five dimensionless parameters in the form

\[
\frac{Q_s}{Q_w} = C\left(\frac{h_j}{D}, \frac{h_j}{d_j}, \frac{q_j}{Q_w}, \frac{\rho_s}{\rho_w}\right)
\]

or
\[ \frac{Q_s}{Q_w} = C\left(\frac{h_j}{d_j}, \frac{q_j}{Q_w}, S \right) \]

Limitations of the experimental apparatus were restrictive and not ideal. This experiment was tested only with one kind of sand specific gravity = 2.69 and one suction pipe diameter of 2.92 inches. With these limitations the relation of the variables are reduced and rewritten to the following:

\[ Q_s = f(Q_w, q_j, d_j, h_j) \]

Using dimensional analysis one can obtain:

\[ \frac{Q_s}{Q_w} = C\left(\frac{h_j}{d_j}, \frac{q_j}{Q_w}\right) \]

This shows that the dimensionless sand transport capacity coefficient \( \frac{Q_s}{Q_w} \) depends on both the dimensionless height of jet coefficient \( \frac{h_j}{Q_w} \) and the dimensionless discharge coefficient \( \frac{q_j}{Q_w} \). As shown in Figures 17 to 20 relations exist between \( \frac{Q_s}{Q_w} \) and \( \frac{q_j}{Q_w} \) (when \( \frac{h_j}{d_j} \) is maintained constant) and similarly between \( \frac{Q_s}{Q_w} \) and \( \frac{h_j}{d_j} \) (when \( \frac{q_j}{Q_w} \) is maintained constant).
EXPERIMENTS

Experimental Apparatus

The schematic diagram of the experimental apparatus is shown in Figure 3. This experimental arrangement consisted of the following principal instruments.

Jet Ejector and Suction Tank

In this experiment, the jet ejector was used to agitate the sand in the suction tank. It consisted of two vertical annular pipes, a suction tank and a centrifugal supply pump A. The inner pipe served as the jet pipe, and the outer annular served as the suction pipe of the centrifugal delivery pump B. The jet pipe could be adjusted to various heights in order to determine an optimum to give the best sand transport capacity of centrifugal delivery pump B. Two sizes, 0.80 in. and 0.65 in., of the inner jet pipe were used in this experiment. The suction pipe was 2.92 in. in diameter and fixed with the mouth of 6 in. above the bottom of the suction tank. The suction tank had a hopper form; its maximum capacity was 60 gallons. The jet ejector and the suction tank are shown on the sketch in Figure 2 and in pictures in Figures 6 and 8.
Figure 3. Experimental apparatus sketches.
**Water Channel**

A channel was used to supply water to the jet pipe by means of centrifugal supply pump A. Channel measurements were 47 ft. long, 1.5 ft. wide and 2 ft. deep. The channel was connected by 1.5 in. pipe in diameter at the bottom of one end to the suction side of the centrifugal supply pump A. The level of water in the channel was kept constant by adding the water from a municipal water tap.

**Centrifugal Supply Pump A**

This pump was provided to supply the water from the water channel and subsequently to agitate the sand in the suction tank through the interior annular jet pipe. This centrifugal pump had a maximum capacity of 16 gpm. The suction pipe and discharge pipe were 1 1/2 in. and 1 1/8 in. in diameter respectively.

**Centrifugal Delivery Pump B**

This centrifugal pump was provided to discharge the sand-water mixture from the suction tank into a screen basket in the weir tank as shown in Figure 7. The pump was not originally designed for pumping sand-water mixtures. Without modification of packing gland, the small size of sand being pumped would be forced into the packing gland and would stop the pump. A clean water source was connected
Figure 4. General view of the experimental apparatus.

Figure 5. Photo of a screen sediment basket being removed from water by a hydraulic lift.
Figure 6. Jet apparatus and suction tank.

Figure 7. Centrifugal delivery pump "B" with two screen sediment baskets in the weir tank.
Figure 8. Experimental set up showing jet apparatus, suction tank, supply sand box and the water supply pipes.
to the packing gland for the continuous flushing of packing gland, making sand-water mixture pumping possible for the pump. The gland water required high pressure to produce a flushing flow to the packing into the pump.

The pump used was SS-H centrifugal type with a closed bronze impeller, 5 1/4 in. in diameter and 0.53 in. in thickness. The suction pipe and discharge pipe were both 2 1/2 in. in diameter. The pump was driven by a 3/4 HP 1740 RPM motor. See Figures 21 to 23 on impeller wear of this pump.

Elbow Meter

An elbow meter was constructed for measuring the water discharge of the centrifugal supply pump A at the elbow as shown on the sketch in Figure 9.

![Elbow Meter](image)

**Figure 9.** Elbow meter.
The elbow meter was an elbow of 1 1/8 in. in diameter and connected to a manometer as shown in Figure 9. Calibration was accomplished by recording the head difference of the manometer and measuring the corresponding discharge by a previously calibrated weir tank. The result of calibration is shown in Table 1 and on curve in Figure 25.

**Weir Tank and Screen Baskets**

The calibrated weir tank as shown in Figure 4 provided measurement of discharge of water from the centrifugal delivery pump B. The weir tank held a maximum capacity of 330 gallons, and had a sharp crest 90° triangular weir at one end, 8 in. in height and 16 in. in length. The weir was calibrated in place volumetrically with discharge corresponding to height above V-crest weir. The resulting calibrations are shown in Table 2 and in Figure 26.

The screen baskets, constructed of 50 mesh screen were used to collect the sand. One, having the capacity of 2.7 ft.³, was used for collecting the sand in a period of time during one run, and another with the capacity of 2.8 ft.³ was used interchangeably. Figure 5 shows one of the screen baskets capacity 2.7 ft.³ being removed from water by a hydraulic lift.
Experimental Procedure

Clean water runs were made to obtain the centrifugal pump main characteristic prior to testing the jet ejector pump with the sand mixture. Runs with clear water were made each time after the impeller was removed for inspection of wear effect on the pump characteristic. The resulting pump characteristics are shown in Tables 6 to 8 and plotted in Figure 24.

In the course of sand tests, two series of investigations were conducted. One dealt with jet diameter of 0.80 in. and the other dealt with the jet size of 0.65 in. Four runs, covering different discharge of the centrifugal delivery pump B in its range of normal operating efficiency, were made at several positions of the jet pipe. Three jet pipe discharge capacities were made at each position of the jet pipe, ranging from zero discharge to the maximum discharge.

In operating the system for each sand run, the following steps were performed.

1. Discharge adjustment of centrifugal supply pump A and delivery pump B to a desired discharge such as 49.4, 58.3 gpm. etc. for pump B and 0, 11 or 16 gpm. for pump A.

2. Water supply was maintained in the suction tank to a constant level about 26 in. above the bottom.

3. Record suction and discharge pressure on the operation of
centrifugal delivery pump B before pumping sand.

4. Sand was maintained gradually into the suction tank to the level of about 8-10 in. above the bottom or 2-4 in. above the suction mouth.

5. After the sand in the discharge pipe had run continuously, the discharge mouth was deflected from one basket to the other to obtain the period of time for one run, then returned to the first basket.

6. Weight of sediment discharge was determined after the basket was removed from water 10 minutes. The weight of wet sand after deducting the tare weight of the basket was recorded.
RESULTS

Table 3 summarizes the experimental data for the sand transport capacity of a centrifugal delivery pump when pumping with and compared with no jet water in operation. Figures 10 to 15 present the sand transport capacity as a function of the jet discharge at the given jet mouth position with the clear water discharge as the parameter. The data is plotted here in order to show the effect of the jet ejector on the sand transport capacity at a given jet mouth position and at a given clear water discharge initially before sand discharge. Figure 16 shows the effect of the size of the jet pipe on the sand transport capacity at the constant jet discharge of 16 gpm. at various jet positions.

The normalized ratio of the experimental results are presented in Table 4 for the jet pipe ratio \( \frac{d_j}{D} \) of 0.274 and in Table 5 for the jet pipe ratio \( \frac{d_j}{D} \) of 0.222. Figure 17 to 20 represent the linear dimensionless ratios plot for the jet pipe ratio \( \frac{d_j}{D} \) of 0.274 at each constant clear water discharge before pumping sand. The data is plotted in this manner to show the effect of the dimensionless ratios \( \frac{q_j}{Q_w} \) and \( \frac{h_j}{d_j} \) on the dimensionless ratio of \( \frac{Q_s}{Q_w} \).
Figure 10. Sand transport capacity vs. clear water discharge before pumping sand, \((d_j = 0.80 \text{ in.}; h_j = 1.00 \text{ in.})\).
Figure 11. Sand transport capacity vs. clear water discharge before pumping sand, \((d_j = 0.80 \text{ in.}; h_j = 10.0 \text{ in.})\).
Figure 12. Sand transport capacity vs. clear water discharge before pumping sand, (d_j = 0.80 in.; h_j = -2.00 in.).
Figure 13. Sand transport capacity vs. clear water discharge before pumping sand, \((d_j = 0.65 \text{ in.}; h_j = 1.00 \text{ in.})\).
Figure 14. Sand transport capacity vs. clear water discharge before pumping sand, \((d_j = 0.65 \text{ in.}; h_j = 10.0 \text{ in.})\).
Figure 15. Sand transport capacity vs. clear water discharge before pumping sand, \((d_j = 0.65 \text{ in.}; h_j = -2.00 \text{ in.})\).
Figure 16. Comparison of sand transport capacity vs. clear water discharge before pumping sand for different sizes of jet pipe.
Data presented in Appendix 1, page 47.

Figure 17. Contour relationships of the dimensionless ratios $Q_s/Q_w$, $q_j/Q_w$ and $h_j/d_j$ ($d/J = 0.274$; $Q_w = 49.4$ gpm).
Figure 18. Contour relationships of the dimensionless ratios $Q_s/Q_w$, $q_j/Q_w$ and $h/d_j$ ($d_j/D = 0.274; Q_w = 58.3$ gpm).

Data presented in Appendix I, page 47.
Data presented in Appendix I, page 47

Figure 19. Contour relationships of the dimensionless ratios \( Q_s/Q_w \), \( q_j/Q_w \) and \( h_j/d_j \) (\( d_j/D = 0.274; Q_w = 72.0 \) gpm.).
Data presented in Appendix I, page 47.

\[ \frac{Q_s}{Q_w} = 0.1800 \]

\[ \frac{Q_s}{Q_w} = 0.1900 \]

\[ \frac{Q_s}{Q_w} = 0.2000 \]

\[ \frac{Q_s}{Q_w} = 0.2100 \]

\[ \frac{Q_s}{Q_w} = 0.2100 \]

\[ \frac{Q_s}{Q_w} = 0.2000 \]

\[ \frac{Q_s}{Q_w} = 0.1900 \]

\[ \frac{Q_s}{Q_w} = 0.1800 \]

Figure 20. Contour relationships of the dimensionless ratios \( \frac{Q_s}{Q_w} \), \( \frac{q_j}{Q_w} \) and \( \frac{h_j}{d_j} \).

(d_j/D = 0.274; Q_w = 85.5 gpm.).
DISCUSSION

Sand Transport Capacity

Pumping of solid-fluid mixtures using the special type of jet apparatus as shown in Figure 2 can be either advantageous or disadvantageous to the sand transport capacity of a centrifugal delivery pump. Limitations of the experimental apparatus made the time for one run during sand testing small, about 20-40 seconds. The measurement of suction pressure and discharge pressure during the sand testing were thus untenable. Subsequently, the pump performance of the centrifugal delivery pump B could not be plotted to show the current effect of operation of the jet apparatus on the sand transport capacity. The results of data are summarized by plotting sand transport capacity vs. clear water discharge before pumping sand as shown in Figures 10 to 15. Here, the sand transport capacity of the centrifugal pump B as using the jet size of 0.80 in. and 0.65 in. in diameter are in qualitative agreement, indicating a satisfactory procedure considering the short time for measurements.

Interesting results of sand transport capacity are shown in Figures 10 and 13. In these figures the tests were operated with the jet suction 1 in. above the discharge suction mouth. These figures show that the sand transport capacity of the centrifugal delivery pump B using the jet water as the agitator is greater compared to operation without the jet for the same clear water discharge before sand running. The
increasing value of the sand transport capacity was about 13-28% for jet pipe of 0.80 in. in diameter, and was about 15-34% for jet pipe of 0.65 in. in diameter as the centrifugal pump B pumping in the range of normal operation efficiency and in the range of jet discharge of 11-16 gpm.

Results are shown, in Figures 11 and 14 for jet pipe 0.80 in. and 0.65 in. in diameter, both using the jet mouth 10 in. above the suction mouth. Indications were that the value of the sand transport capacity of the centrifugal pump B decreased with the jet water in operation. The value of decrease was about 6-14% for the jet pipe of 0.80 in. in diameter and was about 11-16% for the jet pipe of 0.65 in. in diameter as the centrifugal delivery pump B pumping in the range of normal operation efficiency and in the range of jet discharge of 11-16 gpm. This indicated that the jet water did not support pumping the sand-water mixtures but it acted counter current to the sand-water being pumped which in turn retarded the sand transport capacity of centrifugal pump B.

When the jet mouth was placed 2 in. below the suction mouth, indications were that there was not much effect of the jet water on the sand transport capacity of the centrifugal pump B as shown in Figures 12 and 15.

Figures 17 to 20 show that the dimensionless ratio of \( Q_s/Q_w \) is the function of dimensionless ratios \( h_j/d_j \) and \( q_j/Q_w \) as agreeing
with the prediction of interrelationships of variables. The optimum value of \( \frac{Q_s}{Q_w} \) occurred as the value of \( \frac{h_j}{d_j} \) ranging from 0.5 to 2.5 and as the value of \( \frac{q_j}{Q_w} \) ranging from 0.15 to 0.40 as shown in Figures 17 to 20.

**Pump Wear**

As is well known when pumping solid-fluid mixtures, the centrifugal pump is subjected to wear or damage which may be due to corrosion or erosion. It is necessary to consider the velocity distribution within the pump (Stepanoff, 1957) in order to make a correct identification of pump wearing. Normally, the lowest velocity would be at the suction inlet which would be the same as the velocity in the suction pipe, if pipe and suction nozzle are the same. The fluid is accelerated into the eye of the impeller and is discharged from the vane tips at a much higher velocity. In the casing of the pump, velocity is converted back into pressure, and the fluid gradually decelerates from the cut water to the discharge connection. Consideration of velocity would indicate that, in certain internal pump areas, damage would be more severe than the others. This type of damage is caused by erosion. In case of corrosion, the wear is not dependent on the velocity, it depends on the corrosive resistance of the metal. The damage of this type may be quite uniform and independent of velocity distribution.
Stepanoff (1964) stated that "It has been estimated that wear of major parts of centrifugal pumps handling solids varies directly as cube of speed."

The centrifugal pump B used in this experiment, had the closed impeller of bronze type. According to comparison the pictures of the impeller as shown in Figures 21 to 23 which were taken throughout the tests. The impeller showed the high polish and wear in the area of high velocity, at the vane tips and around the suction eye of the impeller. The damage was a result of erosion only. The results of pump performance when pumping clear water at different times are shown in Tables 6 to 8 and plotted in Figure 24 to show the effect of the wear on the pump performance.
Figure 21. Comparative pictures of impeller showing the effect of wear on suction eye side.

(a) Initial picture prior to sand test (impeller weight not available)

(b) Intermediate picture after 24 hrs. slurry pump (impeller weight = 3.38 lbs.)

(c) Final picture after 39 hrs. slurry pump (impeller weight = 3.30 lbs.)
Figure 22. Comparative pictures of impeller showing the effect of wear on gland side.

(a) Initial picture prior to sand test (impeller weight not available)
(b) Intermediate picture after 24 hrs. slurry pump (impeller weight = 3.38 lbs.)
Figure 23. Comparative pictures of impeller showing the effect of wear on side view.

(a) Initial picture prior to sand test (impeller weight not available)

(b) Intermediate picture after 24 hrs. slurry pump (impeller weight = 3.38 lbs.)

(c) Final picture after 39 hrs. slurry pump (impeller weight = 3.30 lbs.)
Figure 24. Characteristic curves of centrifugal delivery pump.
CONCLUSION

A special type of jet apparatus which ejects a water jet downward toward sediment field from within the suction pipe was investigated. The following conclusions are empirically based.

1. As the jet mouth was operated in the position close to the annular suction mouth, the sand transport capacity of the centrifugal pump increased as the jet discharge increased.

2. As the jet mouth was extended above the area close to the annular suction mouth, the sand transport capacity of the centrifugal pump decreased as the jet discharge increased.

3. As the jet mouth was extended below the area close to the annular suction mouth, the sand transport capacity of the centrifugal pump was nearly equal in either case of pumping with the jet or without the jet in operation.

4. The dimensionless ratio of sand transport capacity $Q_s/Q_w$ was affected by the dimensionless ratios of jet discharge $q_j/Q_w$ and height $h_j/d_j$. The optimum value of $Q_s/Q_w$ occurred as the value of $h_j/d_j$ ranging from 0.5 to 2.5 and as the value of $q_j/Q_w$ ranging from 0.15 to 0.40.
RECOMMENDATION

This paper has dealt with a general study of pumping sand water mixture using a jet apparatus as agitator as shown in Figure 2. Without doubt, the work should be extended on this problem. Future work may include the following.

1. Study the effect of the various type of nozzles of the interior jet pipe.
2. Study the effect of the size and type of the suction pipes.
3. Study the effect of the specific gravity of sediment and its gradation on the above pumping operation.
4. Obtain complete prediction of the performance which can serve as the relationship to the prototype.

Industrial Application of These Results

The mechanical means for cleaning mineral ore is oftimes equipped with a feed tank and pumping arrangements similar to those reported in this study (see Figure 2) (Dennen and Wilson, 1949). This operation may be made more economical if the (coal) slurry would be pumped with a jet in operation with the jet mouth position close to the annular suction mouth rather than other positions of the jet mouth.
BIBLIOGRAPHY


Fairbank, Leigh C., Jr. 1940. The effect of material in suspension upon the characteristics of a centrifugal pump. Master's thesis. Berkeley, University of California. 102 numb. leaves. (Microfilm)


APPENDICES
## APPENDIX I

### Table 1. Elbow meter calibration.

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<th>Manometer Reading (in.)</th>
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![Diagram](image-url)
Figure 25. Elbow meter calibration curve.
Table 2. Weir calibration (V-notch type).

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<th>Height of water (ΔH) (ft.)</th>
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Figure 26. Weir calibration curve (V-notch type).

\[ Q \approx 2.63 \Delta H^{2.5} \]
Table 3. Summary of sand transport capacity in gpm. of the pumping test.

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* Obtained from the curves of sand transport capacity vs. clear water discharge before pumping sand.
Table 4. Dimensionless ratios $q_j/Q_w$, $Q_s/Q_w$ and $h_j/d$ on sand pumping test with jet pipe ratio $d_j/D = 0.274$.

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Table 5. Dimensionless ratios $q_j/Q_{w}$, $Q_s/Q_{w}$ and $h_j/d_j$ on sand pumping test with jet pipe ratio $d_j/D = 0.222$.

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| 72.0       | 0.153       | 0.1650      | 0.222      | 0.1694     |           |
| 85.5       | 0.129       | 0.1785      | 0.187      | 0.1878     |           |

| $10.0$     | 0           | 0.1448      | 0.223      | 0.1320      |
| 58.3       | 0.188       | 0.1251      | 0.274      | 0.1182      |
| 85.5       | 0.129       | 0.1415      | 0.187      | 0.1370      |
Table 6. Clear water pumping test (initial calibration).

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<td>10</td>
<td>346</td>
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<td>0</td>
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<td>0.00</td>
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<td>-3.50</td>
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<td>12.24</td>
<td>18.85</td>
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<td>9.94</td>
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<td>1.907</td>
<td>0.379</td>
<td>0.220</td>
<td>74.0</td>
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<td>1.915</td>
<td>0.387</td>
<td>0.230</td>
<td>73.0</td>
<td>10</td>
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<td>0.245</td>
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<td>667</td>
<td>0.893</td>
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</tr>
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</table>
Table 7. Clear water pumping test (intermediate calibration).

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Suction gage</th>
<th>Pressure gage</th>
<th>Pump total head</th>
<th>Water level</th>
<th>Power input to driver</th>
<th>Power output HP</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left leg (in. Hg)</td>
<td>Right leg (in. Hg)</td>
<td>ft. of water</td>
<td>ft. of water</td>
<td>ft. of water</td>
<td>Gage Ht. (ft.)</td>
<td>Ht. above crest (ft.)</td>
</tr>
<tr>
<td>12</td>
<td>+0.05</td>
<td>-0.05</td>
<td>+0.11</td>
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<td></td>
<td>11.4</td>
<td>25.88</td>
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<td>+0.10</td>
<td>-0.22</td>
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<td></td>
<td>10.8</td>
<td>24.93</td>
</tr>
<tr>
<td>14</td>
<td>-0.40</td>
<td>+0.40</td>
<td>-0.87</td>
<td></td>
<td></td>
<td>10.0</td>
<td>22.97</td>
</tr>
<tr>
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<td>+0.65</td>
<td>-1.42</td>
<td></td>
<td></td>
<td>93</td>
<td>21.50</td>
</tr>
<tr>
<td>16</td>
<td>-1.35</td>
<td>+1.35</td>
<td>-2.94</td>
<td></td>
<td></td>
<td>8.0</td>
<td>18.50</td>
</tr>
<tr>
<td>17</td>
<td>-1.80</td>
<td>+1.80</td>
<td>-3.92</td>
<td></td>
<td></td>
<td>7.2</td>
<td>16.62</td>
</tr>
<tr>
<td>18</td>
<td>-2.45</td>
<td>+2.45</td>
<td>-5.34</td>
<td></td>
<td></td>
<td>5.8</td>
<td>13.40</td>
</tr>
<tr>
<td>19</td>
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<td>+3.20</td>
<td>-6.08</td>
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<td></td>
<td>4.6</td>
<td>10.62</td>
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<tr>
<td>20</td>
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<td>+3.75</td>
<td>-8.16</td>
<td></td>
<td></td>
<td>2.7</td>
<td>6.47</td>
</tr>
</tbody>
</table>
Table 8. Clear water pumping test (final calibration).

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Suction gage</th>
<th>Pressure gage</th>
<th>Pump total head</th>
<th>Water level</th>
<th>Power input to driver</th>
<th>Power output</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left (in. Hg)</td>
<td>Right (in. Hg)</td>
<td>(ft. of water)</td>
<td>(ft. of water)</td>
<td>Gage Ht. (ft.)</td>
<td>Ht. above crest (ft.)</td>
<td>Discharge (cfs.)</td>
</tr>
<tr>
<td>21</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>10.9</td>
<td>25.20</td>
<td>25.20</td>
<td>1.528</td>
</tr>
<tr>
<td>22</td>
<td>-0.20</td>
<td>+0.20</td>
<td>0.43</td>
<td>10.2</td>
<td>23.58</td>
<td>24.01</td>
<td>1.763</td>
</tr>
<tr>
<td>23</td>
<td>-0.60</td>
<td>+0.60</td>
<td>1.31</td>
<td>9.3</td>
<td>21.49</td>
<td>22.80</td>
<td>1.809</td>
</tr>
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<td>24</td>
<td>-1.00</td>
<td>+1.00</td>
<td>2.18</td>
<td>8.4</td>
<td>19.40</td>
<td>21.58</td>
<td>1.840</td>
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<td>25</td>
<td>-1.60</td>
<td>+1.60</td>
<td>3.49</td>
<td>7.2</td>
<td>16.61</td>
<td>20.10</td>
<td>1.863</td>
</tr>
<tr>
<td>26</td>
<td>-2.30</td>
<td>+2.30</td>
<td>5.01</td>
<td>5.8</td>
<td>13.40</td>
<td>18.41</td>
<td>1.883</td>
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<tr>
<td>27</td>
<td>-2.95</td>
<td>+2.95</td>
<td>6.41</td>
<td>4.3</td>
<td>9.95</td>
<td>16.36</td>
<td>1.900</td>
</tr>
<tr>
<td>28</td>
<td>-3.75</td>
<td>+3.75</td>
<td>8.16</td>
<td>2.6</td>
<td>6.00</td>
<td>14.16</td>
<td>1.917</td>
</tr>
</tbody>
</table>
APPENDIX II


Measurement of Head. In Figure 27, the pressure gage indicates the pressure at the center of the gage. Likewise the mercury manometer reading is the pressure at the top of the right-hand mercury column.

By applying Bernoulli's equation between the suction and the discharge pipe as shown in the Figure 27

![Diagram of pressure measurement](image)

Figure 27. Measurement of head.
\[
V^2_p s + \frac{V^2_s}{2g} + Z_s = V^2_d + \frac{V^2_d}{2g} + Z_d - H
\]

\[
H = (p_d - p_s) + \left(\frac{V^2_d}{2g} - \frac{V^2_s}{2g}\right) + (Z_d - Z_s)
\]

Since the diameters of the suction pipe and discharge pipe are the same, 2 1/2 in. in diameter.

\[
H = (p_d - p_s) + (Z_d - Z_s)
\]

From the Figure 27, if the center of the pressure gage, the zero gage reading of suction gage and the datum are at the same level.

Therefore

\[
p_d = 2.31 P
\]

\[
p_s = -1.13y + x
\]

\[
Z_d - Z_s = 0
\]

\[
H = 2.31P + 1.13y - x
\]

**Measurement of Discharge.** A triangular weir or V-notch with sharp crest connected to the end of the tank was used to determine the capacity of water from the pump B. Knowing the height above V-notch crest weir, the corresponding discharge of water may be obtained from the calibration curve in Figure 26.
Measurement of Power Input. (ebh) The power input to the driver was measured instead of the power input to the pump by using the kilo-watt hour meter. The power input was calculated by the following formula.

\[
\text{ebh} = \frac{k_h (3600)(N)}{T(746)}
\]

Sand Transport Capacity. \((Q_s)\) Determine the net weight of sand after removed from the water ten minutes by the scale and converted to the dry weight as following.

\[
W_{sd} = \frac{W_{sw}}{R}
\]

The sand transport capacity \((Q_s)\) in gpm. was calculated by the following formula:

\[
Q_s = \frac{W_{sd}(449)}{w(S_s)(T)}
\]

Sample Computation

Pump Performance. (The numerical values in this part apply to Run No. 16 of the clear water pumping test (intermediate calibration).)

a. Observed data (Run No. 16)

Time for one run--85.5 sec.
Suction gage:

Height of \( \text{Hg}_2 \) above zero gage reading (left leg) -- 
1. 35 in.

Height of \( \text{Hg}_2 \) below zero gage reading (right leg) -- 
1. 35 in.

Pressure gage -- 8. 0 psi

Gage height in weir tank -- 1. 848 ft.

Revolutions of kilo watt-hour meter -- 10. 0

b. Head develop by pump \( (H) \)

\[
H = 2. 31P + 1. 13y - x
\]

\[
= 2. 31(8. 0) + 1. 13(2. 70) - \frac{1. 35}{12}
\]

\[
= 18. 50 + 3. 05 - 0. 11
\]

\[
= 21. 44 \text{ ft. of water}
\]

c. Discharge of water \( (Q_w) \)

Height above V-notch crest weir = 1. 848 - 1. 528 = 0. 320 ft.

From curve in Figure 26 gives \( Q_w = 0. 145 \text{ cfs.} \)

\[
Q_w = 0. 145(449) = 65. 1 \text{ gpm.}
\]

d. Power input to driver \( (ebh) \)

\[
ebh = \frac{k}{h} \frac{(3600)N}{T(746)}
\]

\[
= \frac{1}{2} \frac{(3600)10}{85. 5(746)}
\]

\[
= 0. 753 \text{ HP.}
\]
e. Power output (whp)

\[ Q_{whp} = \frac{Q_w H}{550} \]

\[ = \frac{0.145(62.4)21.44}{550} \]

\[ = 0.354 \text{ HP}. \]

f. Efficiency (e)

\[ e = \frac{\text{Power output}(100)}{\text{Power input}} \]

\[ = \frac{0.354(100)}{0.753} \]

\[ = 47.0\% \]

**Sand Transport Capacity.** (The numerical values in this part apply to Run No. 63 on sand pumping test (as \( d_j = 0.65 \text{ in.} \), \( h_j = 10 \text{ in.} \), \( q_j = 0 \text{ gpm.} \) and \( Q_w = 85.5 \text{ gpm.} \).)

g. Observed data (Run No. 63)

Time for one run--20.3 sec.

Weight of initial basket--34.0 lb.

Weight of final basket with sand--161.5 lb.

Gage height in weir tank (before sand run)--1.885 ft.

h. Sand transport capacity \( Q_3 \)

Weight of wet sand \( (W_{sw}) = 161.5 - 34.0 = 127.5 \text{ lb.} \)
Weight of dry sand \( W_{sd} \) = \( \frac{W_{sw}}{R} \)

\[ \frac{127.5}{1.27} = 100.4 \text{ lb.} \]

Sand transport capacity \( Q_s \) = \( \frac{W_{sd}(449)}{w(S_s)(T)} \)

\[ \frac{100.4(449)}{62.4(2.69)(20.3)} = 13.20 \text{ gpm.} \]

i. Clear water discharge \( Q_w \)

Height above V-notch crest weir = 1.885 - 1.528 = 0.357 ft.

From curve in Figure 26 gives \( Q_w = 0.190 \text{ cfs.} \)

\[ Q_w = 0.190(449) = 85.5 \text{ gpm.} \]

**Material Used**

Only one grade of sand was used in this experiment. Size representation and specific gravity of sand were determined by the standard methods specified by the American Society of Testing Material (A. S. T. M.). Ratio of wet and dry sand weight was determined by weighing wet sand after taken from water ten minutes, and dried in the oven with the temperature of 230°F about one day. The ratio of wet and dry sand weight is given in Table 9. The main physical characteristics of sand are given in Table 9. Figure 28 gives the gradation curve of representative material.
Table 9. Summary of sand characteristics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tr>
<td>Specific gravity</td>
<td>2.69</td>
</tr>
<tr>
<td>Ratio of wet and dry sand weight</td>
<td>1.27</td>
</tr>
<tr>
<td>Median diameter $D_{65}$</td>
<td>0.63 mm. (0.0248 in.)</td>
</tr>
<tr>
<td>Settling velocity (for $D_{65}$)</td>
<td>0.245 fps.</td>
</tr>
<tr>
<td>Size of openings in inches</td>
<td>Number of mesh - U. S. standard</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 28. Sediment gradation curve.
APPENDIX III

Nomenclature

\[ \begin{align*}
D &= \text{Inside diameter of the suction pipe (inch).} \\
\text{d}_j &= \text{Inside diameter of the jet pipe (inch).} \\
e &= \text{Efficiency (percent).} \\
\text{ehp} &= \text{Power input to driver (horse power).} \\
H &= \text{Head develop by pump (feet of water).} \\
\text{h}_j &= \text{Height of jet pipe referring to suction mouth (inch).} \\
k_h &= \text{Constant coefficient of kilowatt-hour meter} = \frac{1}{3} \\
N &= \text{Revolution of kilowatt-hour meter in period of time.} \\
P &= \text{Discharge pressure (pound per square inch).} \\
\text{p}_d &= \text{Discharge pressure (feet of water).} \\
\text{p}_s &= \text{Suction pressure (feet of water).} \\
q_j &= \text{Discharge of jet water (gallons per minute).} \\
Q_s &= \text{Sand transport capacity (gallons per minute).} \\
Q_w &= \text{Clear water discharge (gallons per minute).} \\
R &= \text{Ratio of wet sand to dry sand weight.} \\
S_s &= \text{Specific gravity of sand.} \\
T &= \text{A period of time for one run (second).} \\
V_d &= \text{Velocity in discharge pipe (feet per second).} \\
V_s &= \text{Velocity in suction pipe (feet per second).} \\
w &= \text{Unit weight of water (pound per cubic feet).} \\
\text{whp} &= \text{Power output (horse power).} \\
W_{sd} &= \text{Weight of dry solid (pound).}
\end{align*} \]
\( W_{sw} \) = Weight of wet solid (pound).

\[ x = \text{The distance from the top of right hand mercury column to the zero gage reading of the suction gage (inch)}. \]

\[ y = \text{Manometer deflection of the suction gage (inch)}. \]

\( Z_s \) = Elevation of zero gage reading of the suction gage referred to datumn (feet).

\( Z_d \) = Elevation of pressure gage referred to datum (feet).

\( \rho_s \) = Density of solid (pound per cubic feet).

\( \rho_w \) = Liquid density (pound per cubic feet).