MONTANA STATE UNIVERSITY

The effect of chip-shaped particles on pump performance characteristics
by Ken L Page

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF Science in Civil Engineering
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Abstract:
This is a preliminary study of the effects of chip-shaped solids on the performance characteristics of low-head centrifugal pumps. An Allis-Ohalmers 4 x 4 x 9 1/2 LC Pump with two interchangeable impellers, an NSW closed impeller and an NSX open-faced impeller, a Fairbanks-Morse 3-inch model 5422 pump, and a 5-inch Hazelton CTL pump were used in the study.

The pumps were tested at speeds corresponding to those given on the characteristic performance curves furnished by the manufacturers.

The flow rates for each pump were varied from no flow to 600 gallons per minute, Performance tests were run on each pump at each test speed for clear water, for a 10 per cent volumetric concentration of water and chips, and also for a 20 per cent concentration. The three resulting performance curves for each pump speed were plotted and compared to ascertain the effects of the solids on the head, brake horsepower, end efficiehcy of the pump. This study shows that the increase in concentration of a water-chip mixture has the following effects on the characteristic performance of a centrifugal pump?
a) The head developed by the pump at a given discharge increased a small amount with the open impeller and decreased slightly with the closed impeller.

b) The power input required by the pump at a given discharge increased significantly for both impeller types.

c) The pump efficiency at a given discharge decreased an appreciable amount for both types of impellers.

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The pumps used in this study were obtained on loan from the following companies:

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ABSTRACT

This is a preliminary study of the effects of chip-shaped solids on the performance characteristics of low-head centrifugal pumps. An Allis-Chalmers 4 x 4 x $9\frac{1}{2}$ LC Pump with two interchangeable impellers, an NSW closed impeller and an NSX open-faced impeller, a Fairbanks-Morse 3-inch model 5422 pump, and a 5-inch Hazelton CTL pump were used in the study.

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c) The pump efficiency at a given discharge decreased an appreciable amount for both types of impellers.

LIST OF SYMBOLS

A	=	Cross-sectional area of pipe in square feet
b	=	Width of the impeller in feet
BHP	=	Brake horsepower
C	=	Volumetric concentration of chips in water-chip mixture
cfs	=	Cubic feet per second
d	=	Diameter of pipe in inches
D	=	Diameter of pipe in feet
D_i	=	Disc friction losses
d-c	=	Direct current
dv/dr	=	Change in velocity in the radial direction
e	=	Pump efficiency in per cent
E_p	=	Head produced by the pump in feet of fluid flowing
fps	=	Feet per second
g	=	Acceleration of gravity, 32.2 feet per second
gpm	=	Gallons per minute
G_c	=	Specific gravity of the chips
G_m	=	Specific gravity of mercury
G_{wc}	=	Specific gravity of the mixture
G_w	=	Specific gravity of water
H	=	Head developed by the pump
H_i	=	Hydraulic losses
h_L	=	Head loss in feet of fluid flowing
h"	=	Theoretical head produced by the pump
hp	=	Horsepower

L_i	=	Leakage losses
M_i	=	Mechanical losses
mv	=	Millivolt output
p	=	Pressure in pounds per square foot
Q	=	Flow of fluid in cubic feet per second
QM	=	Flow meter chart reading for the water-chip mixture in gpm
Q_r	=	Discharge flow rate at the best efficiency point
QS	=	Flow rate of the solids into the system
QW	=	Flow meter chart reading for the clear water in gpm
r	=	Radius of the impeller in feet
RPM	=	Revolutions per minute
T	=	Input torque in inch-pounds
V	=	Velocity of water in the pipe in feet per second
WHP	=	Water horsepower
Y	=	Manometer deflection in inches
Z	=	Elevation above a datum in feet

<u>Subscripts:</u>

d	=	Discharge side of the pump
s	=	Suction side of the pump

<u>Greek letters:</u>

β	=	Blade angle is degrees
γ	=	Unit weight of water, 62.4 pounds per cubic foot
Δ	=	Amount of change in any quantity
μ	=	Absolute viscosity of a fluid
π	=	A constant, 3.1416
τ	=	Unit shearing stress of a fluid
ω	=	Rotational speed of the pump in radians per second

CHAPTER I

INTRODUCTION

The interest in hydraulic transportation of solids in pipe lines has increased in scope and volume during the last 10 years to the extent that several major companies throughout the country are now engaged in research in this line [5]. The operating experiences of several experimental slurry pipe lines have been very encouraging to the scope of the above mentioned research [13, 21].

Reduction in transportation costs is the main advantage advocated by proponents of the hydraulic transport of solids [14]. An economic feasibility study [8] completed at Montana State University in March 1965 showed that this method of transporting wood chips competes favorably with other methods of transportation. As a result of this feasibility study an experimental program was initiated at Montana State University investigating the hydraulics of transporting wood chips in pipe lines.

This study of the effects of chip-shaped particles on pump performance characteristics is part of the above mentioned experimental program. The program is conducted as part of a cooperative aid agreement between the Forest Engineering Research Branch of the Intermountain Forest and Range Experiment Station, U. S. Forest Service and the Civil Engineering and Engineering Mechanics Department of Montana State University.

Previous studies performed at Montana State University, under the above cooperative agreement, have dealt with the effects of chip-shaped particles on axi-symmetric pipe expansion losses, the specific gravity of saturated wood chips and the effects of chips on the head loss caused by a standard gate valve. Results of these studies are available from the Intermountain Forest and Range Experiment Station of the U. S. Forest Service and the Civil Engineering Department of Montana State University.

This particular phase of the project deals with the effects of a fluid mixture containing rectangular-shaped chips on the performance characteristics of low-head centrifugal pumps designed to handle sewage and trash. Plastic chips were used in the tests to simulate saturated wood chips. The tests were performed at Montana State University in the Civil Engineering Section of Ryon Laboratory.

This study was undertaken to acquire knowledge about the changes in pump performance characteristics while pumping rectangular-shaped, chip-type solids. This will help to determine the power requirements for wood chip pumping projects as well as the type of pump most suitable for pumping water-chip mixtures.

CHAPTER II

REVIEW OF FLOWS OF MIXTURES AND PUMPING

An investigation of the problems of the performance characteristics of pumps caused by water-chip mixtures requires an understanding of flow characteristics of mixtures and pumping problems associated with them. This section covers the flow characteristics of fluids and mixtures, termed rheology, and reviews the progress being made in pumping of solid-liquid mixtures.

A. Rheology of Mixtures.

The branch of science dealing with the mechanics of flow of substances, including solid-liquid mixtures, is called rheology. The rheology of solid-liquid mixtures is extremely complex. This complexity arises from the fact that a solid does not mix homogeneously with a fluid, but retains its own shape and identity. The solid is simply transported by the fluid while conserving its own state and form, except in the case where the solids are very small and are in continuous suspension, as in a colloidal solution.

When the solid particles are extremely small and the concentration high, the mixture displays a property similar to the viscosity of true liquids and the term "apparent viscosity" is attached to this phenomena to differentiate it from the viscosity as defined for Newtonian fluids. The absolute viscosity of a fluid (μ) is defined as the ratio of the unit shearing stress (τ) to the rate of change of velocity in respect to the pipe radius (dv/dr) herein referred to as the rate of shear strain. When the shearing stress is linearly proportional to the rate of shear strain, the fluid is said to be Newtonian. Likewise when the relation between the shearing stress and the rate of shear strain is non-linear the fluid is termed non-Newtonian.

None of the current fluid mechanics textbooks give a discussion of non-Newtonian fluid flow. Such discussions are generally omitted or treated in a manner similar to that of Daugherty and Franzini [3]. "Although there are certain non-Newtonian fluids in which the shear stress varies with the rate of shear, these are not generally of engineering importance." Those engaged in hydraulic transport of solids research agree that non-Newtonian fluids are of "engineering importance". Stepanoff [20] suggests that a stage has been reached where there should be as many rheograms (flow diagrams) as there are non-Newtonian fluids, very much the same as there are tables and charts of physical properties of Newtonian fluids and solid substances. Stepanoff [20] also points out that in rheology "slip" (sudden change of velocity near the pipe wall) and "plug flow" are termed as "anomalies" and are omitted from consideration. However these are part of the main characteristics of the rheology of solid-liquid mixtures.

A characteristic distinction between solids and liquids is the manner in which each can resist shearing stresses. A further distinction among various kinds of fluids can be noted by reference to Fig. 1. As was stated previously, a Newtonian fluid is one for which the shearing stress in linearly proportional to the rate of shear strain and can be represented by a straight line in Fig. 1. The slope of the line is determined by the viscosity of the fluid. An ideal fluid, with no viscosity is represented by the horizontal axis. A fluid which resists flow until it sustains a certain amount of stress can be shown in Fig. 1 by a straight line intersecting the vertical axis at the shear stress at which initial motion occurs. These fluids are generally termed Bingham plastics and once flow has started they behave much the same as a Newtonian fluid. A vast group of non-Newtonian fluids fall between the Newtonian fluids and the Bingham plastics. These are termed psuedo-plastics and they follow what is commonly referred to as the Oswald de Waele model.

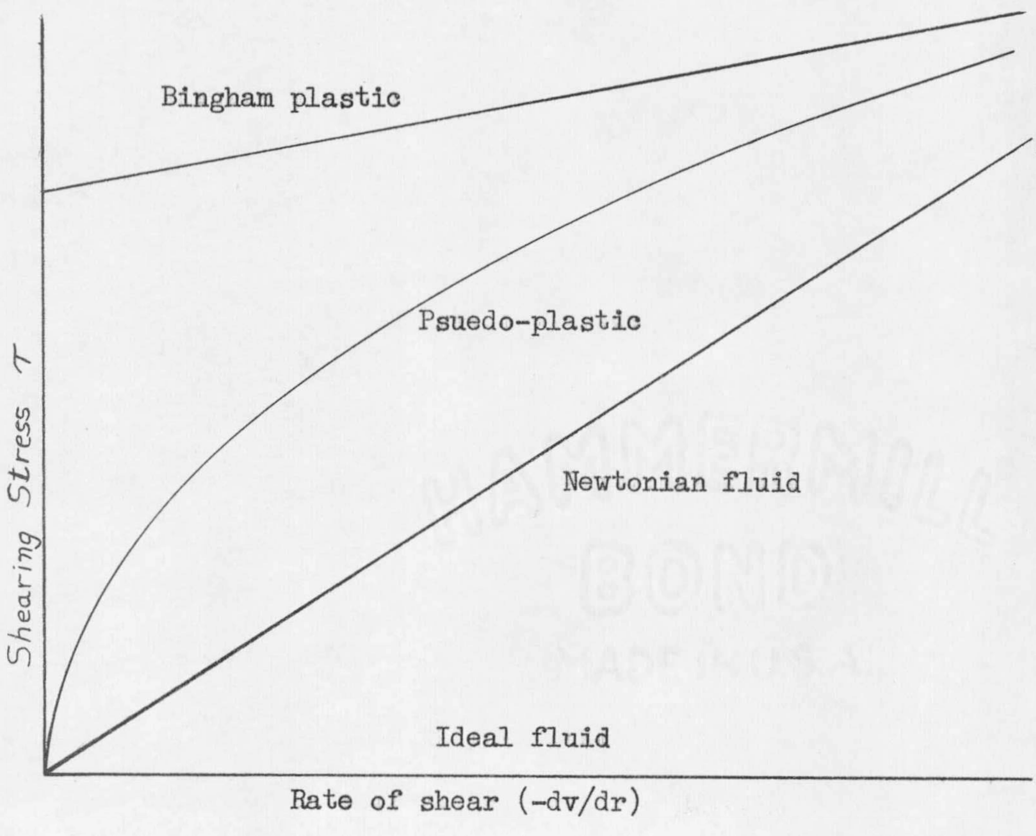

Figure 1 -- Laminar Flow Diagrams

The rheological properties of a mixture composed of water and wood chips have not yet been established. Pulp stock is accepted as an Ostwald de Waele fluid [1]. Stepanoff [20] states that most of the solid-liquid mixtures encountered in the hydraulic transportation of solids have exhibited Bingham properties. It could not be determined from his discussion whether they behaved as a Bingham plastic or as a psuedo-plastic, becoming asymptotic to the Bingham plastic line as the concentration increased. It is the opinion of the author that a mixture of wood chips and water will behave much the same as pulp stock with psuedo-plastic properties. As the concentration is increased to 25-30 per cent plug flow will develop and the mixture should exhibit Bingham plastic properties.

The above discussion points out the complexity of the rheology of fluid-solid mixtures and the small amount of information available pertaining to the non-Newtonian fluids.

The non-Newtonian flow characteristics of a water-chip mixture creates two questions regarding the performance characteristics of a pump. 1) To what extent does the mixture of water and chips affect the pump performance characteristics? 2) Are the effects advantageous or detrimental? A review of the available literature shows that very little has been done in this area to date.

B. Pumping of Mixtures.

The mechanics of flow of Newtonian fluids through closed impellers has been studied and analyzed quite extensively [2, 4, 7, 11, 12, 15, 18]. Research has been done on how the blade angle of the impeller affects the flow characteristics [7]. The effects of the variation in casing size and pump speed upon pump characteristics have been studied and plotted for various pumps [12, 15]. However, the field of centrifugal, closed-impeller, pump design still relies quite heavily on empirical formulae and plots of various parameters derived from past experiments. Strictly mathematical formulae have been developed for this type of design but they are limited to ideal (non-viscous) fluids [7].

Research in the field of pumping solids in a liquid medium has been limited [7, 20]. Several large companies in the United States and Canada are presently engaged in this type of research [5, 8, 14]. At this time they are either not at liberty to, or are unwilling to, publish their results. Very little printed information is available pertaining to the flow of solid-liquid mixtures and the effects of these mixtures on pumps.

Results of previous investigations pertaining to the pumping of clay slurries, using a centrifugal dredge pump with a 4-inch line, have been presented by Herbich and Vallentine [7]. The conclusions presented regarding pump characteristics are as follows:

1) The head developed at a given capacity decreased as the concentration of the solid material in suspension increased.
2) The required power input at a given capacity increased as the concentration of the solid material in suspension increased.
3) The efficiency at a given capacity decreased as the concentration of the solid material in suspension increased.

Similar results included in Herbich and Vallentine's report [7], were noted for a centrifugal pump handling sand-water mixtures.

The literature research conducted as part of this study failed to locate any mathematical development of the mechanics of flow through open-faced impellers.

C. Objectives of the Study.

This study was undertaken to acquire knowledge about the changes in pump performance characteristics while pumping rectangular-shaped, chip-type solids in a water medium. Results of this study should be useful in the design or selection of pumps handling solids. These results will also be useful in predicting power requirements for pumping solids, particularly those pumps used in the hydraulic transportation of wood chips.

CHAPTER III

DEVELOPMENT OF HYPOTHESIS

Pump performance characteristic curves are described by the parameters Q, H, T, and e. The total head developed by the pump (H), the brake horsepower [BHP = T ω /(550 x 12) where T is the shaft input torque in inch-pounds and ω is the rotational speed in radians per second], and the pump efficiency (e) are plotted as ordinates on the same sheet with the discharge capacity (Q) as the abscissa [3, 19].

Any change in one of the first three parameters will affect the pump efficiency, since:

$$e = (Q \times \gamma \times H \times 12)/(T \times \omega) \qquad (3.1)$$

where γ is the unit weight of the fluid being pumped.

The deliberate variation of discharge (Q) and pump speed (ω) under controlled conditions will produce a set of characteristic pump curves for a given pump (Fig. 23 of Appendix C).

The efficiency of centrifugal pumps with open or closed impellers depends upon a number of loss factors. These are generally classified into four groups.

a) Hydraulic losses, H_1: In this group are included the skin friction losses due to the motion of the fluid relative to the impeller and the casing, the shock losses at the impeller entrance and at the discharge into the volute, and the energy dissipated in turbulence generated in these regions. The hydraulic losses are related to the radial component of the fluid velocity in the pump.