The effect of chip-shaped solids on energy losses, in axi-symmetric pipe expansions
by Robert Walter Charley

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Civil Engineering
Montana State University

Abstract:
The primary purpose of this study was to investigate the effect of chip-shaped solids on the energy losses in axi-symmetric pipe expansions and to compare these losses with water alone flowing through the expansion. Since the energy loss hL is calculated using an empirically-determined loss coefficient the study was performed by comparing the value of KL obtained at various concentrations for a given flow rate with that from clear water.

Five separate expansion angles were tested with downstream velocities of 4, 6 and 8 feet per second. The individual velocities were run with solids at volumetric concentrations of 0, 5, 10, 15 and 20%.

At the 4 feet per second velocity the energy loss remained essentially constant for a given expansion as the concentration ranged from 0 to 20%. The higher velocities showed an almost linear decrease in the energy loss as the concentration of solids was increased.

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THE EFFECT OF CHIP-SHAPED SOLIDS ON ENERGY LOSSES IN AXI-SYMMETRIC PIPE EXPANSIONS

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Civil Engineering

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June, 1966

ACKNOWLEDGMENT

This study was part of a project sponsored by the Forest Engineering Research Branch of the Intermountain Forest and Range Experiment Station, U.S. Forest Service, Department of Agriculture. The author wishes to express his gratitude to Dr. William A. Hunt, who with much effort and patience, provided the guidance for this study. His appreciation is also extended to Mr. Ronald Schmidt and Mr. Ronald Carlson for their efforts and advice.

Notable contributions to this study were made by Mr. T. R. Murphy and the personnel of the Mechanical Engineering Department machine shop at Montana State University, and Mr. John Miller and the members of the staff in the Montana State University computing center. For his technical guidance in statistics a special thanks is extended to Mr. Hans Hamann. Appreciation is also extended to the entire Civil Engineering and Engineering Mechanics staff at Montana State University, whose considerations and encouragement were very helpful.

Special recognition is extended to the authors wife, Rachelle, for her patience and typing of the manuscript. A special thanks to the author's mother, Mrs. Zelma Charley, who made his education possible.

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LIST OF SYMBOLS

A - cross sectional area.

B - best fit slope of a straight line.

C - volumetric concentration of solids.

D - pipe diameter.

E - error to test significance of two slopes.

EGL_1 - upstream energy grade line.

EGL_2 - downstream energy grade line.

$(EGL_1)_e$ - elevation of EGL_1 when projected to diffuser entrance.

$(EGL_2)_e$ - elevation of EGL_2 when projected to diffuser entrance.

$(EGL_2)_x$ - elevation of EGL_2 at point x.

Fx - forces in the x direction.

ff - fluid flowing in test section.

fps - feet per second.

g - gravitational acceleration.

gpm - gallons per minute.

h_L - head loss.

HGL - hydraulic grade line.

K_L - loss coefficient.

$(K_L)_c$ - loss coefficient for a given solids concentration.

$(K_L)_o$ - loss coefficient for clear water.

mf - manometer fluid.

n	-	number of observations.
NDS	-	station number of pressure tap immediately upstream from diffuser.
P	-	pressure.
Q	-	flowrate.
QM	-	flowrate of mix.
QW	-	flowrate of water into mix tank.
QS	-	flowrate of solids.
SEGL	-	slope energy grade line.
SHGL	-	slope hydraulic grade line.
S.G.	-	specific gravity.
V	-	mean velocity.
v	-	variable velocity with boundary layer profile.
X	-	distance from station 1 to any given pressure tap.
XR	-	distance from station 1 to diffuser entrance.
Z	-	elevation head.
$\triangle$	-	differential reading or distance.
δ	-	boundary layer thickness.
γ	-	specific weight.
θ	-	expansion angle.
ρ	-	density.
μ	-	viscosity.
$\partial P/\partial x$	-	change in pressure with respect to distance.

ABSTRACT

The primary purpose of this study was to investigate the effect of chip-shaped solids on the energy losses in axi-symmetric pipe expansions and to compare these losses with water alone flowing through the expansion. Since the energy loss h_L is calculated using an empirically-determined loss coefficient K_L, the study was performed by comparing the value of K_L obtained at various concentrations for a given flow rate with that from clear water.

Five separate expansion angles were tested with downstream velocities of 4, 6 and 8 feet per second. The individual velocities were run with solids at volumetric concentrations of 0, 5, 10, 15 and 20%.

At the 4 feet per second velocity the energy loss remained essentially constant for a given expansion as the concentration ranged from 0 to 20%. The higher velocities showed an almost linear decrease in the energy loss as the concentration of solids was increased.

CHAPTER I

INTRODUCTION

A. Need for study

The main purposes of this paper will be to determine the energy losses (head losses) in axi-symmetric flow expansions carrying a mixture of water and relatively large rectangular chip-shaped solids and to compare these losses to expansion losses with clear water flowing. This study was initiated to gain technical knowledge necessary for estimating the head losses in pipe lines which may be used for transporting solids whose density is approximately that of water.

This study is part of a project sponsored by the U.S. Forest Service investigating the hydraulics of transporting

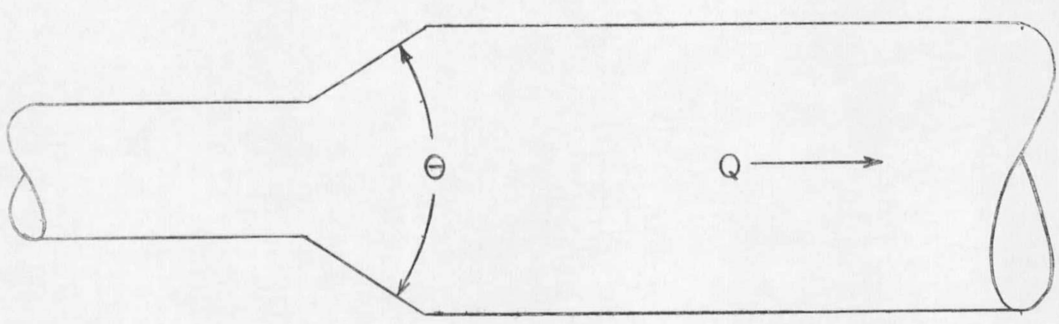

Fig. 1. Axi-symmetric pipe expansion.

wood chips in pipe lines. The potential for moving large quantities of wood chips over long distances in this matter has aroused the interest of several pulp and paper companies in the United States and Canada. Such a study will be a first step in obtaining design data for planning subsequent pipe line systems.

B. Basic head loss equation

The equation most commonly used in engineering calculations for estimating head loss, h_L, for a diffuser shown in Fig. 1, is a modified version of that developed for an abrupt enlargement ($\theta = 180°$). The head loss for an abrupt expansion is:

$$h_L = \frac{(V_1 - V_2)^2}{2g} \qquad (1)$$

The theoretical development of this is in Appendix A.

Theoretically, Eq. (1) is good only for abrupt expansions. Archer and Gibson both found the head loss slightly larger than that indicated by this equation which is then modified by introducing a coefficient K_L as shown by Eq. (2).

$$h_L = K_L \, (V_1 - V_2)^2/2g \qquad (2)$$

K_L is generally called the loss coefficient and is determined empirically. For abrupt expansions, W. H. Archer [1] found that K_L varied from 0.754 to 1.225. Gibson [3] found that for a given area ratio with downstream velocities V_2 greater than 5 feet per second, the loss coefficient was essentially constant. Below 5 feet per second the loss coefficient falls off somewhat rapidly with decreasing velocities. Gibson [2] plotted values of K_L vs. the expansion angle θ for various upstream and downstream area ratios (A_1/A_2).

The purpose of this study is to compare values of K_L for clear water to K_L for a known concentration of a solids-water mixture. For a given flowrate, a change in head loss h_L between clear water and water carrying solids would indicate that K_L is a function of the solids concentration. Then by experimentally determining head loss h_L for different concentrations of solids at given flowrates and solving for K_L from Eq. (2), comparisons of K_L can be obtained.

CHAPTER II

DEVELOPMENT OF HYPOTHESIS

An understanding of the flow characteristics in expansions is necessary to formulate a hypothesis which will relate head losses of clear water to losses for liquid-solid mixtures flowing for such sections and to design an experiment to test this hypothesis.

A literature review was conducted to formulate a hypothesis concerning the change in K_L when solid particles were introduced into the flow. No specific literature on the head losses due to axi-symmetric expansions carrying a liquid-solids mixture could be found. This led to a literature search which pursued two separate areas: (1) The mechanics of head loss in expansions with a liquid flowing, and (2) the transportation of liquid-solid mixtures in pipe lines. A correlation of the two studies allowed for the hypothesis to be formed.

A. Head loss in expansion

The flow of fluids through expansions is a process which converts kinetic energy to pressure head (P/γ). This process is less that one hundred per-cent efficient because of the dissipation of the turbulent energy in the fluid.

This reduced efficiency is a measure of the head loss in the expansion.

The loss in any expanding section can be divided into two parts; that due to friction on the boundaries and that due to the shape or form of the conduit, called the "form loss". The total loss is dependent on the upstream and downstream area ratio [3], the boundary geometry [7], and the velocity distribution [11]. Except for gradual expansions (θ less than 10°) the friction loss is negligible compared to the "form loss".

The "form loss", which is taken to be the total head loss will be explained by the use of Prandtl's [9] boundary layer theory of flat plates which can be modified for circular pipes.

The theoretical boundary layers for flat plates are shown in Figs. 2 and 3. Fig. 2 shows a boundary layer for a zero pressure gradient ($\partial P/\partial x = 0$). This is also the general shape of the boundary layer for a negative pressure gradient, ($\partial P/\partial x < 0$). Fig. 3 is for an adverse pressure gradient ($\partial P/\partial x > 0$).

If the pressure is decreasing ($\partial P/\partial x < 0$) in the downstream direction, the pressure forces and the inertia forces of the free stream flow are in the same direction and com-