COAL/OIL SLURRY FEED PUMP DEVELOPMENT

D. E. Davis
G. S. Wong
Rockwell International/Rocketdyne
Division
Canoga Park, California
H. H. Gilman
Electric Power Research Institute
Palo Alto, California

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ROCKETDYNE'S ADVANCED COAL SLURRY PUMPING PROGRAM

by

Dr. D. E. Davis*, [illegible]. S. Wong,** and H. H. Gilman***

ABSTRACT

The Rocketdyne Division of Rockwell International Corporation is conducting a program for the engineering, fabrication, and testing of an experimental/prototype high-capacity, high-pressure centrifugal slurry feed pump for coal liquefaction purposes. The program is being conducted for the Electric Power Research Institute (EPRI) of Palo Alto, California.

The abrasion problems in a centrifugal slurry pump are primarily due to the manner in which the hard, solid particles contained in the slurry are transported through the hydraulic flow passages within the pump. The abrasive particles can create scraping, grinding, cutting, and sandblasting effects on the various exposed parts of the pump. These critical areas involving abrasion and impact erosion wear problems in a centrifugal pump are being addressed by Rocketdyne. The mechanisms of abrasion and erosion are being studied through hydrodynamic analysis, materials evaluation, and advanced design concepts.

INTRODUCTION

With the impending shortage and increasing cost of energy resources, the conversion of coal to alternate usable forms such as liquefaction and gasification are increasing in importance. Because of this urgent need, the Fossil

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* Program Manager Coal Slurry Pump Program, Rocketdyne Division, Rockwell International Corporation

** Project Engineer, Advanced Pump Systems, Rocketdyne

*** Engineering Manager, Advanced Fossil Power Systems, Electric Power Research Institute

Fuel and Advanced Systems Division of the Electric Power Research Institute is sponsoring a project for early development of a slurry feed pump for coal liquefaction. The coal liquefaction processes presently being considered for commercial development generally require high-pressure coal slurry feed to be supplied to a preheater and reactor at high capacities.

The operating SRC pilot plants at Wilsonville, Alabama, and Tacoma, Washington, currently use conventional low-capacity, reciprocating feed pumps. However, the future scaleup of the present type of feed pump to commercial-size plants would mean using an extremely large number of reciprocating pumps in parallel with the high capital and maintenance costs associated with multiple units. Therefore, high-volume centrifugal pumps producing high pressures are considered to be excellent candidates for addressing the above problems with respect to commercial liquefaction plant feed systems. Although centrifugal pumps are advantageous for high-volume applications, current designs are subject to excessive internal wear because of high velocities.

The primary approach being taken in the current EPRI program is to conduct a comprehensive engineering study of the problems of pumping highly abrasive coal/oil slurries. A concentrated effort is made to identify the problems by making maximum use of the data, knowledge, technology, and experience that exist in industry and at Rocketdyne.

The present test program and design study are continuing with the ultimate goal of providing a reliable centrifugal coal slurry feed pump designed for the following conditions:

● Capacity	5000 gpm
● Feed Rate	50 to 100%
● Pressure	3000 psi
● Temperature	550°F
● Coal/Oil Slurry	
Concentration	50% (by weight)
Specific Gravity	1.20
Viscosity	25 to 50 c.p.
Solid Size	200 mesh

- Operation

Minor Maintenance	6 months
Major Overhaul	1 year

The results and data obtained in the study program on slurry flow, material erosion, and promising high-wear-resistant materials and coatings will be utilized in the prototype slurry pump study to ensure a realizable and practical pump design.

TECHNICAL DISCUSSION

The mechanisms of erosion and abrasion wear, and its relation to velocity and material wear resistance, is now discussed in order to present an understanding of the phenomenon and the design problems it presents. Both hydrodynamic and mechanical design considerations are discussed where abrasion control can be exercised through control of pump internal flow velocities, simple geometry, and generous and continuous bends and curvatures. The effect of pump design parameters on pump internal relative velocities is briefly described. A discussion of promising pump materials, of construction, and hard facing coatings and inserts is also presented.

PUMP ABRASION AND EROSION

Figure 1 illustrates critical areas in a centrifugal pump where abrasion and impact erosion wear problems may be expected. These include abrasion on impeller front shroud and back plate, casing and volute, wear ri[illegible] and seals; and erosion of impeller blade leading and trailing edges and the volute cutwater. Although particle size and shape are factors affecting wear, generally abrasive wear in slurries is found to vary as the 2.7 power of slurry velocity. Thus, if slurry flow velocity is doubled, the erosion wear rate is increased sixfold. In an optimum slurry pump design, therefore, local slurry velocities relative to metal surfaces must be kept low to reduce abrasion and high-velocity impingement against metal surfaces. Also, in appropriate parts of the pump, high hardness material and coating should be used to reduce abrasive wear and ductile materials may be used to reduce impact erosive wear.

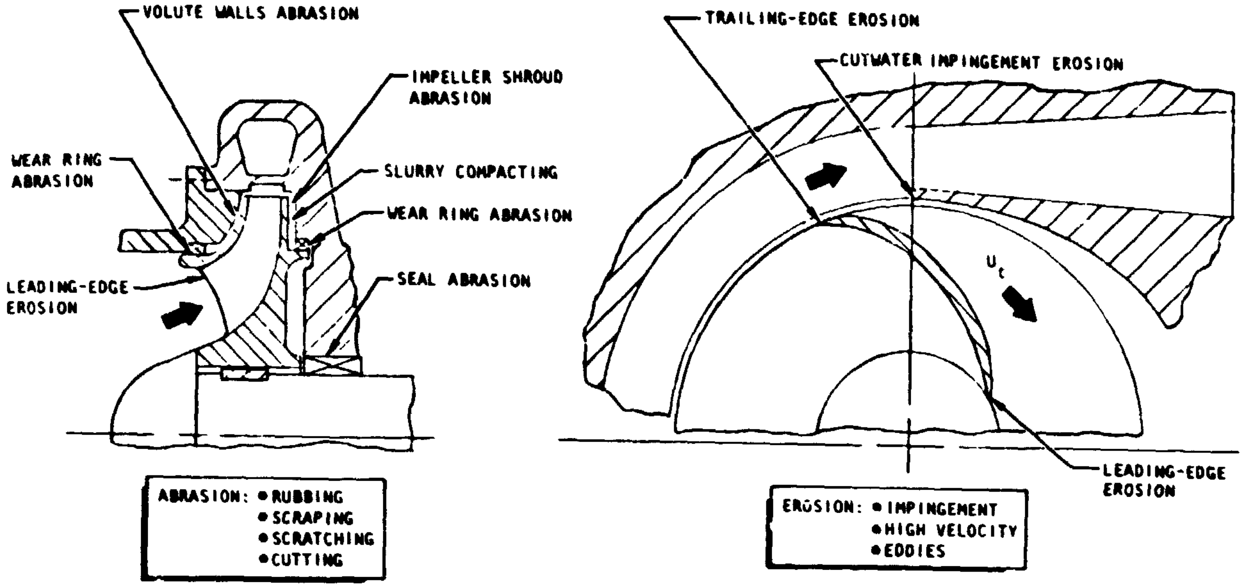

Figure 1. Critical Areas of Wear in a Centrifugal Pump

Despite the high pump tip speed needed to develop high pressures in a minimum number of stages, an understanding of the slurry wear problems will enable the designer to maintain low local slurry velocities near metal surfaces to ensure maximum pump operating life.

HYDRAULIC DESIGN

The maximum relative velocities that occur in pumps are at the impeller inlet eye, at the impeller exit, and at the volute cutwater. Typical velocities as a function of pump parameters flow coefficient (ϕ) and head coefficient (ψ) are shown in Figures 2 and 3. The impeller inlet relative velocity can be minimized by reducing the inlet eye diameter or by introducing inlet whirl in the direction of rotation. Using impeller inlet whirl is desirable since it reduces interstage diffusion requirements in a multistage pump (as the diffuser is not required to remove all the whirl velocity) and permits all impellers to be hydrodynamically identical.

The impeller design affects efficiency directly. The number of blades, entrance angle to the blades, blade thickness and blade contour are all pertinent design elements. Slurry flow velocities are also directly related to

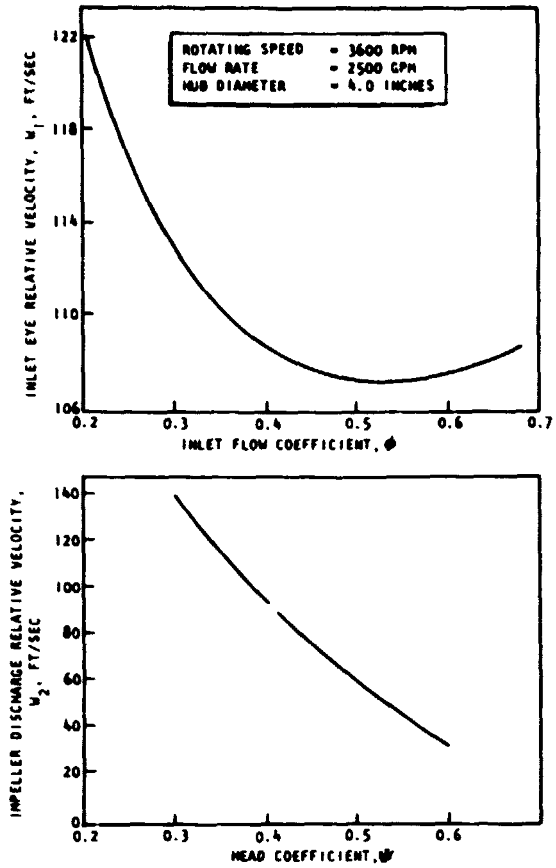

Figure 2. Effect of Pump Design Parameters on Pump Relative Velocities

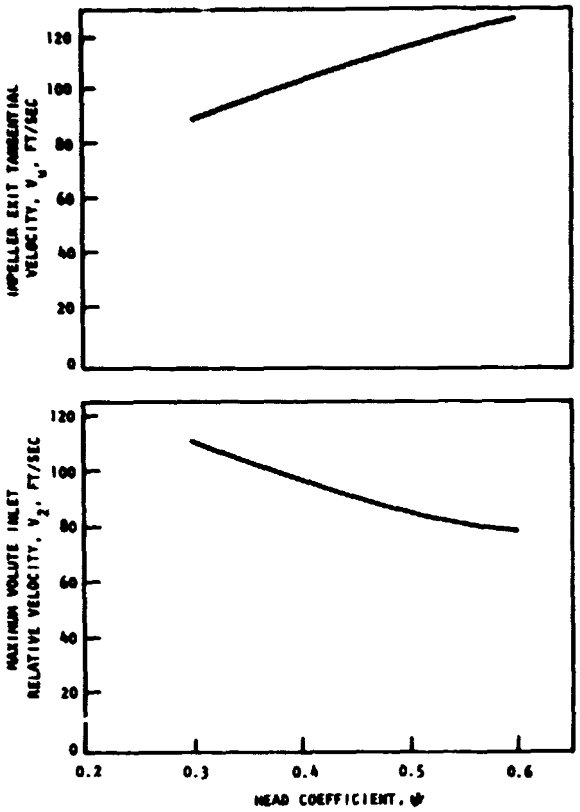

Figure 3. Effect of Pump Head Coefficient on Volute Inlet Relative Velocity

these same design elements. Thus, if an impeller is designed for large flow passage areas by using fewer and thicker blades to reduce slurry velocity, it must be traded off with possible flow separation and eddies, causing localized wear, and loss in hydraulic efficiency that may result.

Impeller front shroud and back plate clearances can be used to control internal velocities and close-clearance abrasion to some extent. Increasing the clearances will minimize potential abrasion wear problems; however, this must be evaluated against reduced efficiency, induced recirculation within the clearances, and secondary flows from high to low pressure areas. Secondary flows themselves will cause localized erosion. Using impeller wear rings is a limited solution to this problem.

As high slurry velocity occurs at the impeller exit or volute inlet, increasing the cutwater clearance at the volute tongue will reduce slurry velocity and impact erosion. However, loss in efficiency must be minimized. Operation of the pump at partial capacity (low flow conditions) must also be kept at a minimum, as accentuated "off-design impingement angle" will cause high impact erosion at the impeller blade and volute cutwater.

WEAR MECHANISM

Erosion of a surface by solid particles entrained in a fluid stream is observed in many different applications such as coal-burning turbines, coal hydrogenation process equipment, coal transport pipelines, suction dredges, and coal-burning, furnace-induced fans. In the present application of a slurry pump for a coal liquefaction process, the solids concentration by weight will be as high as 50 percent. In the study of the wear phenomenon in the pump design, this high concentration of solids at high velocities must be carefully considered.

The two basic types of wear mechanisms that occur in a fluid stream containing solid particles are: ductile erosion (abrasion), and brittle erosion (impact). The former type is one in which the material removal is due entirely to the cutting or displacing action of the particle, similar to grinding or single-tool cutting processes; the latter type is one in which the removal of surface material is caused by a stream of impinging solid particles as in sandblasting, or by liquid impact, as in the case of impeller cavitation.

The mechanical properties involved in the erosion mechanism between the solid particles and material surface include: hardness, plastic flow stress, and Young's modulus. The slurry properties involved are: fluid carrier, concentration. velocity, impingement angle, and particle size distribution, shape, and rotation.

Abrasion

The erosive cutting of ductile materials has been studied analytically by Finnie (Ref. 1). The analysis essentially involves the solution of the equations of motion of the particle into the eroded material under the action of the resisting plastic flow stress of the material. The amount of material the particle removes is then determined from the displacement path of particle in the material. From analyses, the following relationship is obtained for the volume of material removed by particles:

$$Q \simeq C \frac{MV^2}{2} \frac{1}{p} f(\alpha) \tag{1}$$

where

Q = volume of material removed
M = mass of impinging particles
V = particle impinging velocity
P = plastic flow stress
$f(\alpha)$ = a function of impinging angle α to the eroding surface
C = a constant ranging 1/8 to 1/12

Equation (1) indicates that for the erosion of ductile materials or abrasion, the material removal varies linearly with the total quantity of the impinging particles and to the square of the impinging velocity and is independent of the particle size. The only material property that affects the erosion is the plastic flow stress p. It also varies as a function of impinging angle as shown by the dotted curve for aluminum alloy in Figure 4.

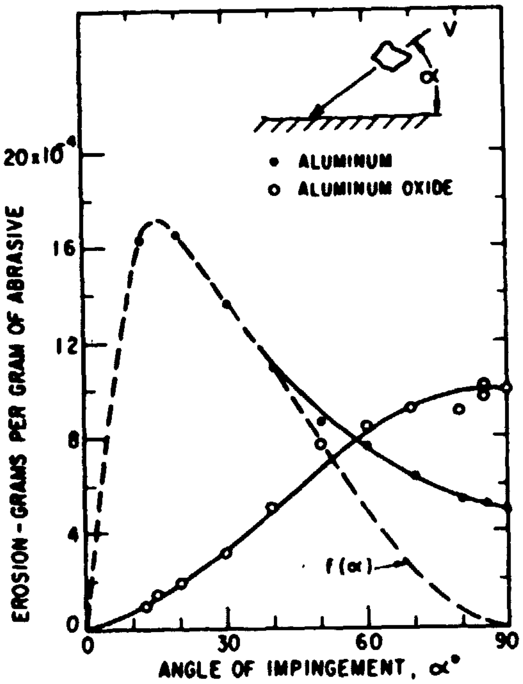

Figure 4. Erosion of Aluminum and High-Density Aluminum Oxide by SiC Particles (120 Mesh and 500 ft/sec)

The variation of the erosion of ductile material with impinging angle α can be explained as follows. At small values of α, erosion increases with α due to increasing normal velocity component and resulting in increasing force of penetration into the material by the particle. At large values of α, the forward cutting velocity component decreases with α, resulting in decreasing forward displacement and erosion. The maximum material removal can be seen to occur at an impinging angle of approximately 20 degrees. The analytical relationship, however, underestimates the material removal at large angles as indicated by the solid curve obtained experimentally. The deviation is attributed generally to the surface roughing and work hardening by the impinging particles at large angles.

Erosion

The study of erosion for brittle materials has been made by Sheldon and Finnie (Ref. 2). The analysis applies the classical Hertz equations to derive the depth of penetration and the resulting stresses in the region around the material indentation and then followed the Weibull theory of mean fracture strength of a material with a volume distribution of flaws to determine the volume of fracture for an impinging angle of 90 degrees. The following relationship for weight removal in cubic centimeter per 10^9 particles was obtained:

$$W = K R^a V^b \tag{2}$$

where

W = weight removal per 10^9 particles
R = mean particle radius
V = impinging velocity with $\alpha = 90$ degrees
K = erosion parameter in cc per 10^9 abrasive particles
a, b = exponents dependent on materials and shape of particles

The erosion weight loss on brittle materials is dependent on particle size and is a function of larger power of the velocity than the weight loss on ductile material. The variation of brittle material erosion with impinging angle is shown by the solid curve for aluminum oxide in Figure 4. Experimental results indicate the size exponent (a) can vary from 3 to 5 and the velocity exponent (b) is close to 2.7.

CANDIDATE MATERIALS

The optimum slurry pump may be comprised of both ductile and brittle materials, with the latter used in selected high-wear areas where impingement angles are low. Since hardness is often a desirable property in low-impingement areas where wear can be a problem, the list of candidates will reflect mostly materials of high hardness. Producibility is another major factor which must be considered for any list of materials, with casting, plasma-spraying, pack or vapor-diffusion processes, welding, brazing, and mechanical joining as possible fabrication methods.

PROGRAM STATUS

A complete engineering study is being made on several potential concepts for the high-pressure, high-capacity, multistage centrifugal pump for coal/oil slurry. This study is further supported by optimization analysis and experimental evaluation of wear-velocity relationships. Detailed design layouts are being made such that: component hydraulic design; structural stress; critical speed dynamics; thrust, seals and bearing loads; and material processes can all be properly evaluated.

The hydraulic design of pump internals emphasizes optimum velocity distributions and minimum highly localized velocities. Generous flow radius of curvature is used and abrupt surface discontinuity is avoided. The mechanical design of the pump utilizes the most appropriate wear-resistant materials, and is configured for simple fabrication and assembly. Since abrasive and erosive wear eventually occurs, the pump design also incorporates convenient disassembly for inspection and parts replacement during minor maintenance and final overhaul.

TABLE 1. POTENTIAL PUMP MATERIALS

Material	Hardness (DPH) (Approximate)
Ductile:	
Stainless Steel (CA6NM)	320
Cast Steel (ASTM216)	250
Titanium (C.P.)	250
Brittle:	
Ni-Hard Cast Iron	650
400C Steel	650
Manganese Steel	580
White Cast Iron	500
Coatings & Inserts	
Silicon Carbide	3000
Silicon Nitride	3000
Tungsten Carbide	2100
Alumina	2000
Tirbaloy T-800	700
Stellite (1016)	650

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1. Finnie, I. - "Erosion of Surfaces by Solid Particles," Wear, Vol. 3, 1960, p. 87.
2. Sheldon, G. L., and I. Finnie - "The Mechanism of Material Removal in the Erosive Cutting of Brittle Materials," Journal of Engineering for Industry, Trans. ASME, Vol. 88, 1966.