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Century 2 – Emerging Technology Conferences

The Century 2 – Emerging Technology Conferences reflect one hundred years of significant achievement in engineering with emphasis on Mechanical Engineering. They focus on emerging technologies, many of which cannot yet be clearly defined.

This volume is one of a series published in conjunction with Century 2. This series is intended to present inventive and innovative work in various engineering disciplines so as to help lead to significant achievements in the next century.

I wish to thank all of those who have participated in this work.

Irwin Berman, PhD, P. E., Chairman
Century 2 – Emerging Technology Conferences

PREFACE

The Century 2 — Emerging Technologies Conference in San Francisco is the highlight of the ASME Centennial Year Celebration marking a record of accomplishment and service. The Society reflects with pride on 100 years of significant achievement while looking to a future of ever greater accomplishment as ASME heads toward its second centruy of existence. As its contribution to the Conference, the four technical committees of the Fluids Engineering Division of ASME have pooled their common interests and resources to sponsor a Symposium on Polyphase Flow and Transport Technology.

Fluids engineering technology is becoming increasingly involved with flow systems characterized by two or more separate phases. Energy generation systems using both conventional and alternative energy sources require continual advancements in the traditional problem of changing water to steam in a complex two phase flow kaleidoscope which changes markedly with geometry, presssure level, orientation, and numerous other factors. Energy conversion devices such as pumps and turbines present new challenges as the energy density of these components is increased. The combustion segment of the energy generation cycle in power plants involves flows with gas and particulate components which require new technologies to ensure both the protection of the environment and the high levels of performance required in the system design. Transportation of solid fuels using liquid flows illustrates another area where polyphase flow plays an important role in our energy economy.

While the world's current concern with energy issues provides readily identifiable examples of important polyphase flow systems, the need for advancement in polyphase technology is also present to improve products which affect our everyday lifestyle. The making of paper, aerosols for agriculture or electronics uses, and the production of chemicals in fluidized beds are only a few examples of technologies strongly dependent upon polyphase flow systems.

The purpose of the present symposium is to provide a forum for the discussion of past developments and an assessment of future directions in this important facet of fluids engineering. As a concurrent activity with the Symposium, an exhibit of products and services related to current polyphase flow technology has been developed to complement the technical sessions.

The Symposium is organized along the following lines of activity. Four keynote presentations are given on different aspects of gas/liquid and gas/particulate flow problems. One paper session is devoted to topics in the flow of suspensions and slurries. Four paper sessions are organized to treat problems in the flows of liquids and gases. Flows in gas/particulate systems are addressed in two technical paper sessions and two panel sessions. The closing activity of the symposium is an audience-participation session which will identify future goals and hopefully suggest possible methods of attaining these goals. These proceedings have been designated as a special publication by ASME and the appearance of a paper herein does not preclude its later publication in an archive journal such as the Journal of Fluids Engineering.

The Organizing Committee extends its thanks to the outside reviewers and session officers who contributed their time and talents on tight schedules to provide comments on the papers. We also acknowledge, with thanks and appreciation, our indebtedness to our symposium secretaries, Ms. Fern Wood and Mr. Greg Carico of West Virginia University, for their day-to-day handling of the many tasks which are an integral part of a successful conference.

The Symposium is the result of a joint effort by T. Heidrick (Conference Vice-Chairman), Y. Reddy and U. Rohatgi of the Fluid Machinery Committee; T. Ariman, C. Crowe and J. Jurewicz of the Polyphase Flow Committee; P. Rothe of the Fluid Transients Committee; and, K. Ghia, H. Weber and R. Bajura of the Fluid Mechanics Committee. Important contributions were also made by R. Arndt, F. Durst and T. Ginsberg in the organization of sessions.

R. A. Bajura
Conference Chairman
Fluids Engineering Division

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THEORETICAL MODELS OF GAS-LIQUID FLOWS

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ABSTRACT

The status of the theoretical representation of gas-liquid flows is reviewed. It is pointed out that existing data cover only a very small sample space of the entire gamut of multiphase phenomena. Moreover, experimental observations are limited to gross parameters; no fine details of any flow regime have been recorded. While analytical methods proliferate, little basis exists for assessing their validity, except under very simple and controlled circumstances.

Although one may believe in "basic equations" at a very fundamental level (e.g. the Navier-Stokes equations for each phase), practical analytical methods necessarily involve the use of assumptions and simplifications in order to make the mathematics tractable. Usable theoretical tools are not expressions of "truth" but are closer to working hypotheses that provide mechanisms for consistently satisfying some macroscopic conservation laws and providing a framework for necessary empiricism.

Since the degrees of freedom allowed by various flow patterns are infinite and "small" changes (such as traces of foaming or nucleation promoters) can have big effects, the predictability of new situations is necessarily poor. The process of building up a useful theory is an art requiring a blend of faith, skepticism, broad knowledge of similar situations, acute observation and a continual interplay between hypothesis and experiment that is often restricted by the costs of investigating the effects of many variables over a range of scale and geometry.

Examples are given of the success and failure of some analytical approaches and the evolution of theory in several situations. Future needs and likely developments are described.

POLYPHASE FLOW IN TURBOMACHINES

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ABSTRACT

The technological problems associated with two-phase or two-component flows are nearly as diverse as the great variety of the flow themselves; couple to this a wide range of pumps, compressors, fans and turbines which are or may be used with these fluids and the resulting spectrum of research and development problems involving polyphase flows in turbomachines is vast indeed. Nevertheless, throughout this wide spectrum there runs connecting threads representing similar physical phenomena and processes. This review paper will attempt to collate the available information in the hope of recognizing the basic mechanisms by viewing a wide range of the spectrum. It will, however, concentrate almost exclusively on liquid/vapor/gas (LVG) mixtures. No minimization of the problems associated with a solid component is intended; rather, some reduction in the total spectrum was necessary.

The problems associated with polyphase flows in turbomachines can be divided into three categories. First, there are the problems of material damage to the machine. Indeed, material damage problems stretch over most of the entire spectrum from the problems of erosional damage with in-line compressors for transport of granular solids (e.g. Rosenecker, Coates and Lucas, 1967, Spencer, Joyce and Faber, 1966), of damage in slurry pumps (e.g. Stepanoff, 1965) and in wet steam turbine operation (e.g. Heymann, 1969 and Krzyanowski, et al, 1971) to the problems of cavitation damage in all kinds of hydraulic machines (e.g. Knapp, Daily and Hammitt, 1970). It is interesting that such problems seem to be least severe in liquid/dispersed gas flows. This trend is reflected in the tendency for cavitation damage rates to be reduced for liquids with elevated total gas content or for liquids at elevated temperatures.

The second category of problems concern the steady state performance of turbomachines with polyphase flow; traditionally tow-phase multipliers have been applied to evaluate the performance characteristics. Until quite recently few attempts were made to understand the basic fluid mechanics and loss processes underlying the values of these multipliers. Some exception to this can be found in the field of cavitation in which basic analytical methods have been moderately successful in predicting performance characteristics and in identifying loss mechanisms (e.g. Stripling and Acosta, 1962, Cooper 1967). Another example are the shock-associated losses in wet-stream turbine operation discussed by Comfort and Crowe (1979); interestingly there appears to be some analogy between these losses and those associated with cavitation collapse regions (Stripling, 1962). It is becoming clear that a better understanding of the different types of two-phase flow pattern which occur in turbomachines and the dependence on the loading conditions is a necessary prerequisite for more accurate performance predictions. For example, axial flow pumps ingesting a gas/liquid two component flow appear to exhibit relatively abrupt performance breakdown when the flow coefficient is decreased or the blade loading increased. This appears analogous to cavitation performance breakdown and is associated with a dramatic change in the flow pattern. In this regard one should also note that the flow pattern at inlet can have a significant effect upon performance (Runstadler, 1976).

The third category of problems involves the frequent occurrence of instabilities and oscillatory flows in turbomachines with LVG flows. Some of these instabilities have counterparts in the single phase flow surge and stall phenomena which occur when the head/flow characteristic has a positive slope (Csanady, 1964). On the other hand, the auto-oscillation phenomena observed with cavitating pumps usually occurs when this slope is negative. The answer here lies in at least a qualitative knowledge of the dynamic as opposed to quasi-static characteristics of turbomachines with polyphase flow. It would appear that many flows with phase change (for example a cavitating pump, Ng and Brennan 1978) can exhibit "active" rather than "passive" dynamic characteristics and are therefore capable of exciting instabilities in the hydraulic systems in which they occur. Much remains to be learned about these

problems, and indeed in the whole area of turbomachine performance with polyphase flow. If this review can highlight some specific areas of potentially valuable research it will have served its purpose.

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EXPERIMENTAL STUDIES OF PARTICULATE TWO-PHASE FLOWS USING LASER-DOPPLER TECHNIQUES

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ABSTRACT

Basic studies of the transport of solid and liquid particles by gaseous flows and the motion of solid and gas particles in liquid flows have been the subject of numerous scientific and engineering investigations. This fact indicates the far-reaching interest in understanding simple flows of this kind as a basic for a deeper insight into the nature of more complex two-phase flows, such as sand and snow storms and the conveyance of plant pollen by winds. In addition, basic information on solid and liquid particle behaviours in turbulent flows will also be valuable to treat more accurately "man made" particulate two-phase flows which are associated with the dispersion of emission products in the atmosphere, in lakes, rivers and the sea. Hence, results obtained in laboratory particulate two-phase systems are likely to find far-reaching applications in treatment of more complex flows.

Carefully conducted experiments with particulate two-phase flows clearly reveal that meaningful results on particle dynamics can be obtained only when related to specific particle size distributions, the shape of particles, the local particle concentration, and to the intrinsic density of the suspended particles relative to the density of the flowing fluid. These properties can only be studied, however, when suitable measuring techniques are available to locally measure the aforementioned parameters, that describe particulate flow systems. Hence, attention has been focused for many years on measuring techniques that accurately measure local particle size distributions, particle concentrations and the velocity distributions of the fluid and the suspended particles. Laser-Doppler techniques have been suggested for such measurements and it has turned out that these techniques work satisfactorily in particulate flow systems in which spherical particles are suspended. In systems of this kind information can be obtained on local properties such as:

(a) instantaneous velocity of the flowing fluid
(b) instantaneous velocity of suspended particles
(c) size distribution of suspended particles
(d) concentration os suspended particles

The present paper provides an introduction into the application of Laser-Doppler anemometers to investigations of particulate flow systems. The basic principles of LDA-measurements in particulate two-phase flows are outlined and it is shown that correct LDA-measurements require the optical system to consist of two parts that permit the information from the fluid velocity field to be separated from the information relating to the properties of the moving particles. The various information on particulate flow systems which is contained in the optical signals is explained and electronic processing systems are introduced that permit this information to be extracted.

The paper describes the application of Laser-Doppler anemometers to particulate flows and presents results that were obtained for a laminar bubble driven liquid flow and for a turbulent gas flow of suspended particles. Implications of these results to improve the present knowledge on particle motion in turbulent flows are provided.

NUMERICAL MODELS FOR GAS-PARTICLE FLOWS

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ABSTRACT

Over the past few years, there have been significant advances in the development of numerical models for gas-particles flows. This paper first identifies those phenomena peculiar to gas-particle (or droplet) flows, reviews the numerical schemes proposed to model such flows, and points to future developments.

The mechanics of the particulate phase in a gas particle flow is dependent on relative effects of aerodynamic forces and particle-particle collisions on the particles' motion. Aerodynamic forces typically predominate in disperse gas-particle flow in a duct whereas particle-particle collisions are the major concern in dense phase flows. A non-dimensional parameter relating particle and flow field parameters is introduced to assess the relative magnitudes of these effects.

Essentially, the numerical models for disperse gas-particle flows can be divided into two categories; those which treat the particle field as a continuum and those that treat the particle field as an assembly of particle trajectories. The advantage of the first approach is that the computational scheme for single phase continuum flow is already available. Also, it is easier to incorporate empirical models for particle dispersion due to turbulence. A major disadvantage is the difficulty in incorporating the history of the particle (temperature, composition, etc.) and establishing meaningful boundary conditions for particle concentration. The advantage of the particle-trajectory approach is particle history effects are a natural outcome of the scheme. The major difficulty with particle-trajectory approach is the inclusion of particle dispersion due to turbulence.

One of the most promising future techniques is the utilization of Monte Carlo methods for particle motion. At present, this approach is expensive because of the large number of particles needed to achieve a stationary distribution. With the advent of faster computer facilities, the Monte Carlo approach will become more popular.

EXPERIMENTAL MEASUREMENT OF ACCELERATED EROSION IN A SLURRY POT TESTER

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ABSTRACT

An apparatus is described and experimental measurements are reported for the accelerated erosion testing of three steel alloys by coal and silicon carbide suspensions in kerosene. The measurements are correlated on the basis of dimensional analysis considerations, with empirical constants in the correlation determined through least squares polynomial regression of the data. The high speed nature of the tests yields results which are essentially independent of viscous effects in the present configuration. Various observations related to the fluid mechanics, temperature and water content of the particle suspension are discussed. Recommendations are made for the construction of an improved apparatus for standardized accelerated erosion testing of ductile materials.

NOMENCLATURE

C	Concentration (gr/cm^3)
dC_S/dt	Rate of erosive wear (gr/cm^2-sec)
D	Equivalent diameter (cm)
R	Reynolds number
S	Yield stress or hardness (dynes/cm^2)
t	Time (sec)
V	Velocity (cm/sec)
δ	Characteristic viscous layer thickness (cm)
Δ	Weight loss per unit area (gr/cm^2)
μ	Viscosity (gr/cm-sec)
ρ	Mass density (gr/cm^3)

SUBSCRIPTS

C	Refers to cylindrical metal test sample
F	Refers to liquid phase
P	Refers to solid particle phase
S	Refers to eroded metal sample ($\equiv$ C for cylindrically shaped test sample)

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[3]Emeritus Professor of Mechanical Engineering

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SUPERSCRIPTS

*	Denotes relative to liquid phase velocity

ACCELERATED EROSION TESTING

The Need

Slurry transport is a necessary part of coal liquefaction processes. However, the motion of suspended coal particles and various associated solid contaminants is the cause for significant erosive wear in flow components such as contractions, valves, bends, tee junctions and related pumping and slurry processing equipment. Although the problem of erosive wear is of considerable industrial importance, there is a lack of appropriate, reliable and consistent experimental information to assist in the design and optimization of slurry transport equipment for coal liquefaction processes.

The parameters governing erosion phenomena are numerous and their relative importance in systems undergoing erosive wear varies depending on the different flow configurations and their physical characteristics. This accounts, in part, for the difficulties encountered in attempting to establish useful experiments which will simulate conditions of practical interest and also yield meaningful and reproducible data. The situation is further aggravated by the low rates at which erosive wear generally takes place in practice, requiring lengthy tests or, to reduce time of test duration for equally precise measurements, the imposition of unduly accelerated erosion conditions.

Testing under conditions of accelerated erosion is desireable because it allows the rapid accumulation of experimental results. However, in conceiving an accelerated erosion experiment, care must be taken to ensure that the data derived from the experiment relates to the system of practical interest. If, in some way, the experiment has constraints which limit the applicability and, therefore, usefulness of the measurements, these must be known and understood.

Pitfalls

Various pitfalls, which are not readily obvious, beset the conception of a useful accelerated erosion experiment. These relate to the question of whether or not geometrical and dynamical similarity exist between the experimental configuration and the full-scale system it purports to model. A simple but significant example will clarify this point. Consider an industrial slurry flow component in which there exists a fluid layer near the component wall, δ, where viscous effects strongly influence the structure and speed of the liquid and particle motions. The thickness of this viscous layer could well be in the range $1 \lesssim \delta/Dp \lesssim 100$, where Dp is an equivalent particle diameter in the slurry flow. Under conditions of accelerated erosion, a geometrically similar flow component might yield $\delta/D_p \lesssim 1$ in a laboratory test; for example, by retaining the original particle size distribution in the reduced scale model. In the laboratory experiment one would find that the rate of erosion is independent of δ and, therefore, that viscous effects in the region of the eroded wall are not mitigating erosive wear significantly. It is clear that this and related results derived from such a laboratory model really correspond to a large-scale flow component in which, indeed, $\delta/Dp \lesssim 1$. The laboratory results do not necessarily relate to the phenomena arising in the industrial flow component originally conceived, for which a more appropriate reduced scale model is required.

Standardization

In conceiving an accelerated erosion experiment, it must be ensured that appropriate and sufficiently accurate control is exercised over all variables affecting the experiment. For example, if small amounts of water strongly influence the erosive characteristics of coal particles, then accurate knowledge of the particle water content is imperative for a meaningful interpretation of measured results. Likewise, temperature, particle concentration and size distribution, viscosity, and particle and fluid phase velocities are important. Because the purpose of an accelerated erosion device is to force erosive wear at an accelerated pace, inadequate control of variables affecting the experiment can lead to serious measurement errors and erroneous interpretation. Thus, it is of utmost importance that standardization of equipment and experimental procedure be impressed upon present, and especially future, experimentation. Given the number of variables influencing erosion and the variety of complex situations where the problem arises, it is obvious that standardization of equipment and methodology will not readily nor uniformily be achieved.

The present investigation stems from the need to provide experimental information of practical value which, at the same time, will bear on some of the fundamental issues affecting erosion phenomena. The study is the result of one of several ongoing research projects presently being conducted by the Coal Liquefaction Alloy Test Program Group at the Lawrence Berkeley Laboratory and involves the experimental determination of material wear under conditions of accelerated erosion. One of the purposes of this communication, therefore, is to outline a material wear testing device of considerable interest to us and in which we believe useful experiments of general applicability can be performed under standardized and carefully controlled conditions.

Earlier Work

There is an abundant literature on erosion-corrosion of metals by slurries. Test devices include loops (1,2,3) and slurry pot systems (4,5,6). Test loops are attractive because they include components such as pumps, valves, bends and piping which are important in process systems. Accelerated wear tests, say in 24 hours, can be obtained by means of radioactive inserts, but this may be prohibitively expensive (1). More commonly, tests may require 1000 hours. Wear may be measured by radioactive pickup, by micrometer thickness measurements, by weighing components or inserts, by chemical analysis of the slurry, and by electrical resistance tests (on probes). Pot tests are made with a resin flask or beaker in which a slurry is agitated by a propeller stirrer. Test specimens may be the stirring propeller or often a small flat metal specimen placed tangent to the rotating slurry. Since these studies have generally been in aqueous systems at ambient temperatures, the corrosion component of wear has been pronounced, and corrosion mitigation is often the main purpose of the test. Thus, slurry pot tests have been useful in coping with corrosion-erosion of aqueous coal slurries, indicating the importance of de-aeration and the effectiveness and concentration of inhibitors. In fact, slurry pot tests correlate better than loop tests with field performance in coal-water slurry pipelines.

In many pot studies the fluid mechanics are poorly defined, but this is generally recognized and improved systems have been used (7).

DESCRIPTION OF THE SLURRY POT TESTER AND EXPERIMENTAL METHODOLOGY

Slurry Pot Tester

In the present work, accelerated erosion conditions were attained in the slurry pot tester depicted photographically in Figure 1-a and schematically in Figure 1-b. The tester consists of a brass cylindrical tank with detachable lid of dimensions and characteristics shown in the Figures. A slurry of initially known physical properties was contained in the tester. It was fluidized by rotating propeller blades attached to a steel shaft aligned along the cylinder axis of symmetry. Two tubular metal samples 2" long and 1/8" o.d. (5.08 cm, 0.318 cm) were separately attached to symmetrically positioned flat side arms extending horizontally from the steel shaft. The shaft was made to rotate at a fixed r.p.m. by a 3/4 hp motor equipped with variable speed regulator. A ten-tooth gear mounted on the shaft allowed measurement of shaft rotation (to within $\pm$ 1 count) by means of magnetic pick-up connected to a digital counter. Steel baffles attached to the inside walls of the cylinder ensured good mixing of the slurry by opposing the vortical motion induced by the rotating samples and the shaft-propeller assembly.

Temperature within the tester was kept constant at $25^{\circ}C \pm 1^{\circ}C$ by electric blanket heating combined with the flow of coolant water through a coil resting on the bottom wall of the tester. Temperature was monitored at one point in the flow by inserting a thermocouple protected by a stainless steel sheath through the tester lid.

Experimental Methodology

Coal and silicon carbide particles were sieved on Tyler testing sieves to obtain the size ranges of interest in the experiment. Particle samples were then dehydrated in an electric oven, through which Argon gas was made to flow, for 2-4 hours at $95\text{-}105^{\circ}C$.