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NEW TECHNOLOGY FOR FLUID DYNAMIC MEASUREMENTS IN GAS-LIQUID-SOLID THREE-PHASE FLOW REACTORS

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NEW TECHNOLOGY FOR FLUID DYNAMIC MEASUREMENTS IN GAS-LIQUID-SOLID THREE-PHASE FLOW REACTORS

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PROPOSAL FOR PHASE I

INTRODUCTION

To improve the knowledge of fluid dynamics inside commercial gas-liquid-solid three-phase flow reactors, CANMET proposes to form a consortium with industrial partners

- to develop a multiple-beam gamma-ray technology to measure the fluid dynamic parameters in upgraders at processing condition,
- to apply this technology for studying the effect of fluid dynamics on the processes,
- to assist industry in developing comprehensive reactor models for the optimization of commercial upgraders.

The proposed consortium is expected to evolve in three phases outlined below. Participants would have the option to renew membership after each phase.

Phase I. Develop a dual-beam gamma-ray interrogation densitometer and test it using a 5 cm ID three-phase fluidized bed column; a system capable of measuring fluid dynamic properties including holdups, bubble size and solid size distributions in a laboratory-scale reactor will be developed.

Phase II. Verify the developed equipment and techniques in a pilot plant reactor at process conditions; refine the gamma-ray technology and examine the effect of operating parameters on the fluid dynamics.

Phase III. Examine the capability of the densitometer in commercial reactor applications by using a 30 cm ID cold three-phase fluidized bed column; optimize the dual-beam system for large-scale reactors and develop semi-empirical models to assist in the interpretation of data to be obtained in large-scale reactors.

OBJECTIVE

The objective is to develop a new gamma-ray densitometry technique for simultaneously measuring gas, liquid and solid holdups and other fluid dynamic parameters in three-phase flow fluidized bed reactors at process conditions. The initial phase would focus on the development of the necessary instrumentation using a cold model fluidized bed column. Subsequent phases would demonstrate the new technique by using a pilot plant bitumen hydrocracker then a large-scale simulation column.

BACKGROUND

Slurry bubble column reactors and three-phase fluidized bed reactors are commonly used in the upgrading of heavy oils via the hydrogen addition approach. The former is employed in hydrocracking processes using finely dispersed additive to prevent coke formation, e.g., the CANMET Hydrocracking Process, whereas the latter includes processes using ebullated catalyst bed reactors to enhance hydrogenation, e.g., LC-Fining or H-Oil processes. In either system, the phase holdups and their distributions in the reactor have a direct effect on the conversion and product yields. Fundamentally, the bubble properties (size, rise velocity and surface tension) can provide basic information for interpreting bubble characteristics in bubble columns and three-phase fluidized beds. Since these parameters control the effective reactor volume, mixing, and mass transfer of hydrogen in the upgrader, it is important that they be monitored on-line.

Although many correlations derived from results obtained in cold model systems were reported for predicting some of the above-mentioned fluid dynamic parameters in multi-phase flows, in general, these correlations are incapable of predicting the behaviour of complicated hydrocarbon mixtures at high temperatures and pressures. Therefore, direct measurement of fluid dynamic data at reaction conditions is necessary to provide the information required for scale-up, control or optimization of the process. Because of the difficulty in installing detectors in reactors operating at high temperatures and pressures, available probes for multi-phase flow measurements are not adequate.

CANMET has successfully developed a gamma-ray interrogation technique by extending traditional single narrow-beam densitometry to measure the fluid dynamic parameters at processing conditions in gas-slurry two-phase hydrocracking reactors. The technique measures variations of density as a function of time and space caused by the passage of gas bubbles. Holdups, flow regimes and bubble size distributions in hydrocrackers can be simultaneously determined.

In catalytic hydrocrackers, three distinct phases exist, i.e., gas, liquid and solids. An extra independent variable is now added compared with the gas-slurry two-phase system. The single narrow-beam technique can no longer provide an absolute measurement of all three holdups and other fluid dynamic parameters. To directly measure the fluid dynamic parameters without perturbing the plant operation, we propose to develop a dual-beam gamma-ray densitometer. The practicality of a multiple-beam gamma-ray system in commercial ebullated bed upgraders is based on the fact that the multiple gamma-ray sources normally installed for catalyst bed height control may also be used for fluid dynamic measurements. Thus, it is anticipated that the new technique would be applicable to existing commercial units without extensive modification of the reactor hardware.

WORKING PRINCIPLE AND INSTRUMENTS

The principle of the proposed technique is similar to that for Laser Doppler Velocimeters (LDV). However, instead of using the Mie scattering signals from the Doppler effect between the moving particles and laser light, the gamma-ray attenuation caused by the Compton scattering by materials in the flow field as a function of time will be determined. Special statistical methods will be developed to distinguish the attenuation by particles (solids or gas bubbles) at a given location and a specific time from one another. The data will be treated according to statistical principles and the results will be related to the properties of bubbles and solids to derive the fluid dynamic parameters.

At least two gamma-ray beams are required. Preferably one of them would have three dimensional (3-D) scanning capability. The radiation energies of gamma rays can be the same or different, e.g., two ^{137}Cs sources, two ^{60}Co sources, or a ^{137}Cs and a ^{60}Co sources. The gamma-ray beams in CANMET's development unit will be 3-D adjustable in the cylindrical coordinates. A transversal and rotational table with vertical scanning capability will be designed and constructed. A ^{137}Cs source from the single-beam system is available and an additional source will be purchased. Computer based multichannel analyzers are available for data acquisition and software for interpreting single-beam interrogation data is also available. Statistical methods and software will be developed for analyzing the dual-beam data.

To develop the instrument in Phase I, a gas-liquid-solid flow field must be provided. A 5 cm ID three-phase fluidized bed column will be constructed for initial use. After completion of the first phase, participants can apply the technology in their own operations and/or join Phase II of the program, in which the technique will be demonstrated and refined at CANMET's pilot plant unit. A 30 cm ID glass column will be set up for optimizing the laboratory unit and developing an industrial-scale densitometer in Phase III.

BENEFITS

Industrial members of the consortium share only 50% of the risk in this exploratory R&D, as CANMET will match the total industrial contribution.

Deliverables:

- Semi-annual progress reports and final report for each phase.
- Description of the technique and software.
- Frequent technical meetings and discussions.

Key benefits to consortium members:

- Members will be given the right to use the developed CANMET multi-beam gamma-ray interrogation technology in their own organizations.
- Member companies can steer the program to their specific needs/interests through a Management Committee made up of one representative from each organization.
- CANMET will provide 50% of the total funding resulting in significant leverage of research funds.
- The capability of gamma-ray densitometers for catalyst bed height level control in client's ebullated bed hydrocrackers may be extended to include the measurements of fluid dynamic parameters.
- Industry staff can be seconded to CANMET/ERL to learn particular skills and participate in the experiments; Facilitate technology transfer.
- Participants can obtain assistance from CANMET for parallel projects.

CONSORTIUM MEMBERSHIP/COSTS

Because this new technique is generic and will have a wide range of industrial applications, CANMET will attempt to form a consortium comprising CANMET and sponsoring members. This will provide the maximum leveraging of industry's financial contribution, although joint agreements will be considered.

Members could include oil, coal and chemical companies, or engineering companies. CANMET will be the sole performer. It is estimated that the cost of Phase I will be approximately $200K, excluding capital acquisitions. A membership fee of $50K per year is proposed. The number of participants and their contributions will determine the total level of effort, since CANMET will match contributions from industry. Semi-annual Management Committee meetings will be held to steer the program.

EXPERTISE AND R&D FACILITIES

CANMET's unique facilities and experience in developing heavy oil upgrading processes will provide the impetus for this consortium. In addition to the cold model columns which will be used for instrument development, pilot plants with tubular reactors up to 18 L, 7.5 cm ID and CSTR's up to 10 L are available for process development and instrument testing. A comprehensive description of facilities is available upon request.

Dr. Dirkson Liu will be the project leader. Dr. Liu is a chemical engineer and chemical physicist and is a senior member of the team of research scientists in ERL's Heavy Oil Upgrading Section, a group composed of more than 20 research scientists and engineers. He has extensive laboratory and commercial scale R&D experience in heavy oil upgrading, reaction engineering and nuclear reactor safety, as well as in physical chemistry and spectroscopy. He is the principal author of more than 60 reports and publications and is co-author of many others. As part of his R&D career in heavy oil and coal upgrading, he led the development of the CANMET gamma-ray interrogation method for fluid dynamic measurements in hydrocracking reactors and now leads the development of a process control system for highly exothermic upgrading processes. He is also a registered engineer in APEO.

INFORMATION

If you would like more information or are interested in joining this consortium please contact:

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