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Interfacial Shear and Stability in Two-Phase Flow

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Knowledge of the characteristics of the flow of two fluid phases with a common interface is necessary to the design of many types of industrial equipment. This type of flow occurs in most of the chemical engineering unit operations. A review of the literature in this field indicates that most investigators have been concerned with the characteristics of specific flow configurations, as determined by a given piece of equipment. The specific nature of the resulting information makes difficult its generalization to new types of equipment. It was, therefore, felt that the time had arrived for a more fundamental investigation of the energy losses and exchanges as well as the stability of fluid-fluid interfaces. A prerequisite to such a study is test equipment in which both the interfacial area and the respective flow areas are measurable.

The investigation reported herein was concerned with the characteristics of the air-water interface existing in the stratified flow of the two phases through a horizontal two-inch pipe. Experimental tests were made with water flowing under stationary air, air flowing over stationary water, and the co-current flow of both phases. Measurements were made of the air pressure drop, the liquid depth, the interfacial gradient, and the gas-phase velocity distribution. These measurements made possible the evaluation of the frictional energy lost by each phase at the pipe wall as well as the energy lost by the gas and gained by the liquid at the common interface.

The energy loss at the pipe wall in each phase exhibits characteristics similar to those in single-phase flow. When the interface is smooth, the energy lost by the gas at that surface is almost identical to that which would be lost at a smooth stationary wall. This energy is transmitted undiminished to the liquid phase. However, in the case of interfacial waves, the water surface exhibits the characteristics of a rough solid surface, and some fraction of the energy lost by the gas is irretrievably lost at the interface.

The pressure-drop characteristics of the horizontal stratified type of flow are strikingly similar to those of packed columns, and indicate that the "loading" point in the latter type of equipment is caused by interfacial wave formation. The flooding of such columns is apparently caused by the breaking of the interfacial waves.

Theoretical considerations indicate that, for a given gas-liquid system, the point of wave formation is conditioned by the liquid depth, the relative velocity between the two fluids, and, like the laminar-turbulent transition point in single-phase flow, the extent of external disturbances. Comparison of wave formation in the flow of air and water through vertical and horizontal tubes with "loading" in packed columns indicates that interfacial waves, giving a hydrodynamically rough surface, form at a relative velocity of 10 to 15 ft./sec. This value increases slightly with decreasing liquid depth.

It is recommended that shear and stability, as well as mass and heat transfer rates, at fluid-fluid interfaces be investigated further for air-water and other two-phase systems. The apparatus used in the present investigation should be modified by the substitution of a test section having a rectangular cross section of high aspect ratio. This would eliminate the slight asymmetrical-flow effects found in the circular tube.

Plate Efficiencies in the Separation of C_4 Hydrocarbons by Extractive Distillation with Furfural

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Average Murphree plate efficiencies were determined in a 13-inch diameter, ten tray, pressure distillation column used to separate isobutane from 1-butene in the presence of furfural-water solutions as the separating agent in an extractive distillation operation. The trays, each containing 13 bubble caps, were specially designed to simulate the type of contacting obtained in the plant tower at the Neches Butane Products Company.

The experimental investigation consisted essentially of four individual series of runs in which the vapor velocity was varied (and the solvent circulation rate varied proportionally) while all of the other conditions were held as constant as possible, for each given series.

The approximate ranges of average operating variables, bracketing the conditions of the isobutane solvent tower at Neches (Happel et al., Trans. Am. Inst. Am. Chem. Engrs., *42*, 189 (1946)), were as follows: column F-factor (column vapor velocity in ft. per sec. multiplied by the square root of the vapor density in lb. per cu. ft.), 0.13 to 0.82; column temperature, 111 to 147° F.; total C_4 hydrocarbon concentration in the liquid, 12 to 29 mole %, corresponding to column pressures of 40 to 100 lb./sq. in. gage; concentration of water in the solvent (on a hydrocarbon-free basis), 0 to 9 wt. %; solvent circulation rate, 9 to 38 gal./min.

Over the entire relatively wide range of operating variables studied, Murphree plate efficiencies, averaged over four trays, varied between 47 and 61%, excluding the results of a single run carried out under partial flooding conditions. Corresponding local efficiencies ranged between 39 and 51%, an overall variation of only 12%.

When computed on a common basis, only a relatively small difference in plate efficiencies is indicated for the experimental and isobutane solvent towers at Neches. In the light of the experimental runs it is difficult to reconcile the considerably lower efficiencies reported for the n-butane and butadiene solvent towers. However, since rigorous comparisons between these towers and the experimental results are not possible, the need for additional experimental work employing different hydrocarbon pairs involving n-butane and butadiene, preceded by careful reevaluation of the plant tower performances in terms of plate efficiencies, is pointed out.

The experimental overall plate efficiencies were correlated by the method of O'Connell with maximum deviations of 15% in the case of the low temperature runs (Series II) and only 10% for all of the other runs. Application of the equation of Walter and Sherwood to four of the anhydrous runs gave somewhat poorer agreement than by the above correlation. Very poor correlation of the experimental results by the method of Drickamer and Bradford was obtained, the latter indicating much lower efficiencies.

While application of the method of Geddes also showed very poor agreement with the experimental results, although it must be recognized that the physical data required for its application were far from being adequate, it was the only correlation that verified qualitatively the negligible effect of temperature on plate effi-

ciency, in contrast to all of the other less fundamental correlations. Theoretical explanations are offered for the poor quantitative predictions of this method in this case.

Reactions of Benzpinacolyl Alcohol and Studies on Related Compounds

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The action of various oxidizing agents including potassium permanganate in acetic acid, potassium permanganate in acetone, selenium dioxide in acetic acid, lead tetraacetate in a mixture of acetic acid, and acetic anhydride on benzpinacolyl alcohol was studied. The highest percentage of anomalous oxidation products was obtained when using lead tetraacetate at high temperature. No oxidation occurred when using selenium dioxide or potassium permanganate in acetone.

When benzpinacolyl alcohol reacted with thionyl chloride, the retropinacolone rearrangement took place, forming tetraphenylethylene. Benzpinacolyl alcohol cleaved with alcoholic potassium hydroxide or with sodium, producing triphenylmethane and benzaldehyde. No methylation of benzpinacolyl alcohol to the corresponding ether occurred with diazomethane alone or when employing aluminum isopropoxide as a catalyst.

Acetic acid, acetic acid and lead acetate, or acetic anhydride did not dehydrate benzpinacolyl alcohol. On the other hand, iodine and acetic acid dehydrated the alcohol to tetraphenylethylene in quantitative yields.

The action of iodine in acetic acid, iodine in methylene chloride, acetic anhydride and sulfuric acid, potassium iodide in acetic acid, iodine and sodium acetate in acetic acid, and zinc and acids was studied with various aromatic pinacols.

With para-toluenesulfonic acid, iodine in acetic acid, potassium iodide in acetic acid, and iodine and sodium acetate in acetic acid, the tendency was for those pinacols containing substituents on the aromatic nuclei which have a predominate electron release to undergo the normal pinacol-pinacolone rearrangement. For the pinacols containing substituents on the aromatic nuclei which have only a very small electron release, the tendency was for cleavage to occur. When using a mixture of sulfuric acid and acetic an-

hydride, and with iodine in methylene chloride, neither rearrangement or cleavage took place.

The highest percentage of cleavage was encountered with iodine and sodium acetate in acetic acid, whereas the greatest amount of rearrangement took place with paratoluenesulfonic acid. A tentative mechanism is proposed to explain the oxidation of aromatic pinacols, as well as the familiar rearrangement. A relationship is shown between the electrostatic effect of substituents on the aromatic nuclei and the amount of oxidation which occurs.

While tetraphenylethylene oxide showed signs of rearranging to beta-benzopinacolone when treated with methyl alcohol and sulfuric acid, no reaction occurred when using methyl alcohol and metallic sodium, or ethyl magnesium bromide in an attempt to open the oxide linkage.

Beta-benzopinacolone was not oxidized with chromic anhydride and acetic acid nor with potassium permanganate and acetic acid. Cleavage occurred, and benzoic acid, triphenylmethane and benzhydrol were formed when an attempt was made to reduce the pinacolone with sodium hydroxide, zinc dust, and ethyl alcohol. A reinvestigation of the action of magnesium subiodide with beta-benzopinacolone appeared to indicate the formation of the pinacol of beta-benzopinacolone.

Flexural Testing of Plastics

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Flexural strength is one of the important properties of plastic materials which must be known in order that they may be used effectively in structural applications. The effect of test variables, such as loading edge radius, beam overhang, horizontal thrust existing at the supports, curvature of the loaded beam, and the natural variability of beams of plastic materials, are subjects of interest to those who measure flexural strength, and the present investigation was directed toward a study of these factors.

A hydraulic Baldwin-Southwark universal testing machine was used to conduct the tests in a room controlled at 77° F., 50% relative humidity. Paper-base and cloth-base phenolic laminates were used as typical stiff plastics, while vulcanized fibre and cellulose acetate were used as typical "ductile" materials. A few other materials were tested also, but the emphasis was kept on the

laminates listed above because only the laminates are at present strong enough for extensive structural application.

Studies of the effects of different loading edge radii indicate that the radii used have a considerable influence on observed values of the modulus of rupture. Increasing the radii leads to an increase in the load-to-break. As a result of explorations concerning the amount of beam overhang, it is concluded that this variable has no appreciable effect on flexural strength provided the overhang is at least equal to 6% of the span, the minimum value investigated. Tests conducted with lubricated end supports and with "dry" end supports show that the frictional forces developed at the supports are negligible, at least for the one material so tested (a paper-base phenolic laminate). The variability in physical properties of commercial sheets of plastic materials was found to be appreciable. In some cases the standard deviation of the modulus of rupture amounted to as much as 6% of the mean strength value. Surveys of eight commercial sheets are given in Figures 33 to 55, and the results are summarized in Table VII. The patterns are seen to be quite irregular.

A theoretical derivation of the influence of the radii of the end supports on the breaking load of a beam is given. The principal assumption basic to this derivation is that the span shortening which occurs during bending is the only significant effect of varying the radii. By assuming the absence of frictional forces at the supports, it was likewise possible to arrive at an estimate of the horizontal forces that develop at the supports. This derivation is given also. The horizontal reactions estimated from the angles assumed by the ends of the beams agreed qualitatively with those calculated from flexural formulae based on purely elastic deformation. The apparent weakening effect of increasing ratios of span to depth is due to the stresses introduced by the bending moment caused by the horizontal reactions at the beam supports.

Data are presented to show that the effect of indentation of the plastic at the supports on the measured beam deflection is ordinarily negligible. The theoretical corrections called for because of excessive beam curvature are shown to be negligible also, except for very high span-depth ratios.

A numerical example is presented to illustrate the application of the theoretical developments.