REFERENCES

1. Argo, W. B., and Smith, J. M., Chem. Engr. Progress, *49*, 443 (1953).
2. Bras, G. H. P., Pet. Refiner *35*, (3) 191 (1956).
3. Brooke, M., Pet. Refiner, *35*, (3) 183 (1956).
4. Brown, G. G., and co-authors, "Unit Operations," John Wiley and Sons Inc., New York (1950).
5. Cichelli, M. T., and Boucher, D. F., Chem. Engr. Progress, *52*, 213 (1956).
6. Clarke, L., and Winston, R. E., Chem. Engr. Progress, *51*, 147 (1955).
7. Coldiron, D. C., Albright, L. F., and Alexander, L. G., paper at Amer. Chem. Soc. Meeting, Dallas (1956).
8. Coppage, J. E., and London, A. L., Chem. Engr. Progress, *52*; 57-F (1956).
9. Donahue, D. A., Pet. Refiner, *34*, (8) 94 (1955); *34*, (10) 129 (1955); *34*, (11) 175 (1955); and *35*, (1) 155 (1956).
10. Eckert, E. R. G., Ind. Eng. Chem., *46*, 932 (1954).
11. Eckert, E. R. G., Hartnett, J. P., and Isbin, H. S., Ind. Eng. Chem., *47*, 647 (1955).
12. Eckert, E. R. G., Hartnett, J. P., Isbin, H. S., and Schneider, P. J., Ind. Eng. Chem., *48*, 655 (1956).
13. Forbes, M. C., Pet. Refiner, *35*, (4) 185 (1956).
14. Garwin, L., and Smith, B. D., Chem. Engr. Progr., *49*, 591 (1953).
15. Gutswiller, G. E., Pet. Refiner, *35* (3), 189 (1956).
16. Hanratty, T. J., A. I. Ch. E. Journal, *2*, 42 (1956).
17. Harvey, B. F., and Foust, A. S., "Heat Transfer—Atlantic City," Chem. Engr. Progress, Symposium Series, *49*, no. 5, 77 (1953).
18. Hobson, M., and Weber, J. H., Ind. Eng. Chem., *46*, 2290 (1954).
19. Hoffman, H. W., "1953 Heat Transfer and Fluid Mechanics Institute," p. 83, Stanford University Press, Stanford, Calif. (1953).
20. Hougen, O. A., and Watson, K. M., "Chemical Process Principles," Part III, pp. 1031–1046 (1947).
21. Ingebo, R. D., Chem. Engr. Progress, *48*, 403 (1952).
22. Jakob, M., "Heat Transfer," John Wiley and Sons Inc., New York (1949).
23. Kreith, F., "1953 Heat Transfer and Fluid Mechanics Institute," p. 111, Stanford University Press, Stanford, Calif. (1953).
24. Larson, R. F., "1953 Heat Transfer and Fluid Mechanics Institute," p. 163, Stanford University Press, Stanford, Calif. (1953).
25. Lee, D. C., Dorsey, J. W., Moore, G. Z., and Mayfield, F. D., Chem. Engr. Progress, *52*, 160 (1956).
26. Lemlich, R., Ind. Eng. Chem., *47*, 1175 (1955).
27. Leva, M., and Grummer, M., Chem. Eng. Progress, *48*, 307 (1952).
28. Lynch, E. P., "Heat Transfer—Atlantic City," Chem. Engr. Progress, Symposium Series, *49*, no. 5, 121 (1953).
29. Marshall, W. R. Jr., "Atomization and Spray Drying," Chem. Engr. Progress, Monograph Series, *50*, no. 2 (1954).
30. McAdams, W. H., "Heat Transmission," 3rd ed., McGraw-Hill Book Company, New York (1954).
31. McCarthy, L. J., Chem. Engr. Progress, *52*, 97-M (1956).
32. Michley, H. S., and Fairbanks, D. F., A. I. Ch.E. Journal, *1*, 374 (1955).
33. Miller, P., Byrnes, J. J., and Benforado, D. M., A. I. Ch. E. Journal, *1*, 501 (1955).
34. Perry, J. H. (editor), "Chemical Engineers' Handbook," 3rd ed., McGraw-Hill Book Company, New York (1950).
35. Plautz, D. A., and Johnstone, H. F., A. I. Ch. E. Journal, *1*, 193 (1955).
36. Rohsenow, W. M., "1953 Heat Transfer and Fluid Mechanics Institute," p. 123, Stanford University Press, Stanford, Calif. (1953).
37. Satterfield, C. N., Resnick, H., and Wentworth, R. L., Chem. Engr. Progress, *50*, 460 and 504 (1954).
38. Schweppe, J. L., and Foust, A. S., "Heat Transfer—Atlantic City," Chem. Engr. Progress, Symposium Series, *49*, no. 5, 77 (1953).
39. Stack, T. G., and Frieden, J. E., Chem. Engr. Progress, *48*, 409 (1952).
40. Toomey, R. D., and Johnstone, J. F., "Heat Transfer—Atlantic City," Chem. Engr. Progress, Symposium Series, *49*, no. 5, 51 (1953).
41. Weatherby, J. J., Pet. Refiner, *35*, (4) 175 (1956).
42. West, F. B., and Taylor, A. T., Chem. Engr. Progress, *48*, 39 (1952).
43. Whitesell, J. M., and Durando, A., Pet. Refiner, *35*, (3) 186 (1956).

Pumps and Compressors

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IN MOST OIL PROCESSING and chemical plants, progress would stop almost completely if it were not for pumps and compressors which maintain fluid flow through the equipment. The number and types of pumps used are almost endless, and recent developments in pumping are numerous. Within the last few years many studies have been made in the nuclear and aeronautical fields to develop pumping devices for liquids at high temperatures, such as molten metals and salts, and for air at fairly low pressures (63, 64, 65). In most cases those studies will not be of immediate value to the oil processing industry although they do give a better understanding of pump theory and operation.

A concentrated effort is now being made to standardize pumping equipment in the chemical industry. The subcommittee on pumps for the American Institute of Chemical Engineers (68) prepared and circulated a questionnaire to pump users. Most of the users were satisfied with the pump performances based on water, but a majority thought there was a need for more data for viscous fluids. Although most users indicated the present pumps were in general satisfactory, they voiced a need for specific improvements. It is estimated (5) that pump standardization will save the chemical industry $6,800,000 a year. Undoubtedly some of the dissatisfaction with the present pumps results from incorrect and inadequate pump selections. The correct choice of a pump for a particular problem is far from easy since many variables must be considered (27). A complete list of process specifications should be prepared and should include fluid characteristics, inlet and outlet pressures, flexibility of operations desired, etc. (36). The scaling up of pump sizes remains a problem. Mitchell (39) indicates that a type of pump satisfactory in the pilot plant is not always so in the full-size plant. In scaling up the pump size, the pump characteristics often change. Hutton (23) reports however that model tests are satisfactory for determining the efficiencies of some large-scale pumps and turbines. The pump manufacturers are attempting to improve their product and service (41). Standardization of pump designs will be expensive to the manufacturer, but the trend appears to be in that direction.

A brief survey was made of the various types of pumps and compressors that are of particular interest in the oil processing industry. New developments are also outlined.

Pumps for Liquids

Reciprocating Pumps. Reciprocating pumps are one type of "positive displacement" pumps (7, 47). The basic design consists of a piston, plunger, or bucket that passes back and forth in a cylinder and displaces the fluid in the cylinder. Reciprocating pumps have been designed that are satisfactory for viscous liquids, but in general they are not. A power-driven reciprocating pump gives uniform fluid delivery over wide ranges of pressures. A steam-driven pump has high efficiencies over a wide range of operating conditions and has flexibility of capacity, head, and speed. Disadvantages of reciprocating pumps include high first cost, large floor requirement, noisy operation, and relatively high maintenance costs.

Within the last few years numerous pilot plants have been built and used for exploratory studies of reaction rates and mechanisms at high pressures. Pumping has proven to be one of the bottlenecks in these plants. Sheen and Fell (53) describe a reciprocating pump that will deliver 3–3,000 ml./hr. of fluid at 0–1,000 p.s.i. Jones (29) describes a pump to obtain fluid pressures of 10,000–30,000 p.s.i. The volume of the fluid delivered can be varied by changing the piston displacement. It appears that design modifications will allow the pump to be used to even higher pressures. Hiteshue and Clark (21) have developed a pump for pumping liquids or slurries to 2,000–10,000 p.s.i. When coal-oil slurries were used, the packing of the pump had to be replaced about every 500–2,000 hrs.

Rotary Pumps. Rotary pumps are those pumps which combine a rotary movement of the working parts with positive displacement (7, 47). Pumps in this category include gear, lobe, vane, and screw pumps. They are capable of developing high heads and relatively constant flows. These pumps are unsatisfactory for slurries because of the close tolerance of the pumps, but they are used for viscous liquids including oils and fats.

Centrifugal Pumps. Centrifugal pumps are widely used in the chemical and oil processing industries (7, 47). Their primary advantages are simplicity, low first costs, uniform (non-pulsating) flow, small floor space, low maintenance expenses, quiet operation, and adaptability to a motor or turbine drive. Their pumping rates and efficiencies however vary significantly with the head developed. The head developed by a simple centrifugal pump is generally quite low compared to that which a reciprocating pump can develop. Liquids of all viscosities, gases, and even slurries can be pumped, but the pump design varies with the fluid being handled. The pump consists essentially of a rotating impeller. The fluid enters at the axis and is discharged through a radial port.

Mann (37) compares the horizontal and vertical type of pumps. The advantages of a vertical pump are less floor space, no priming, less net positive suction head (NPSH), and probably more flexibility. Horizontal pumps have the advantages of more headroom, easier inspections and maintenance, and better lubrication.

The evaluation of the mechanical design of end-suction centrifugal pumps is discussed by Ullock (60). Pumps show symptoms of failure when trouble is experienced with their bearings, shafts, or shaft sleeves. In many cases these failures result from inadequate mechanical design. Although poor hydraulic performance is quite easy to detect, poor mechanical performance is not. Pump shafts have generally been designed solely on the basis of horsepower stransmitted. The study by Ullock proves this is often inadequate. A properly designed pump should operate satisfactorily up to 3,500 revolutions per minute. Ullock emphasizes however that a centrifugal pump should only be operated within the range of conditions specified by the manufacturer. Factors which he used in evaluating a pump are discussed in detail. They include unbalanced radial loads, bearing load, bearing life, shaft deflection, and axial loads on both sides of the impeller. Further studies by Ullock, Reynolds, and Hudson (61) were made on the mechanical design of centrifugal pumps. They describe a method for measuring shaft deflections of the pump. This deflection is caused by impeller weight and unbalanced radial forces in the pump casing. Such deflections tend to cause leakage and scoring of the shaft at the packing gland. Eventually the bearings will fail. The situation can be improved by increasing the diameter of the shaft at the overhang and using bearings of larger size.

Stuffing box leakage is a persistent problem in operating centrifugal pumps. Sniffen (56) describes the selection and installation of pump seals. Factors to be considered include the fluid, temperature, pressure, and stuffing-box design. Certain synthetic rubbers and fluorocarbon compounds are finding widespread use as seal materials. Methods of minimizing packing failures are reported by Coopey (11) and Norton (46). In most cases the trouble results from incorrect packing installment or improper design of the packing gland. Walmsley and Ward (62) discuss the use of double mechanical seals. These seals are frequently useful where conventional seals are unsatisfatcory, and almost anything can be sealed by this arrangement. A second liquid is used in the space between the seals at a pressure generally slightly above that of the fluid inside the pump. The second fluid provides lubrication. Auxiliary pumps, lines, etc., must be provided to circulate the second liquid, and they, of course, increase the cost. In certain cases double mechanical seals are justified though. The design and development of a sealless pump is reported by Litzenberg and White (34). The pump is essentially built within the motor. The pump impeller is directly attached to the rotor of the motor. Both the rotor and the impeller rotate in the fluid being pumped. Design characteristics of pumps manufactured by the Chempump Corporation are reported. These pumps should prove of importance in those operations in which stuffing box leakage has been a problem.

Pumps for High-Temperature Fluids. Several types of pumps have been developed within the last few years for pumping fluids at high temperatures, particularly molten metals. These pumps are used extensively in nuclear engineering projects, but they will probably find use in conventional chemical industries too.

A centrifugal pump for liquids and gases up to 1,500°F. is described by Savage and Cobb (52). The sealing problem was one of the most difficult to solve. A frozen seal was found to be applicable in the case of sodium and lead. The liquid being pumped is made to form the closure by cooling to the solid state. The result is the shaft rides in a very thin film of molten material. It was found that bearings and seal boxes must be manufactured to exact specifications. Cygan and Stelle (14) recently reported on the design and operation of freeze-seal pumps and valves. Designs for sealing sodium at temperatures above 1,200°F. have been satisfactorily tested. The centrifugal pump developed by Clark (9) will handle liquid metals up to 750°F. The seal life was about 2,000 hrs., and it was unnecessary to cool the shaft. The capacity of the pump was 400 g.p.m.

Electromagnetic pumps are uniquely suited for liquid metals. No seals or stuffing boxes, and (at least in theory) no moving parts, other than the fluid, are needed. The fluids for these pumps must be electrical conductors. The electrical current flows through the fluid at right angles to a magnetic field. This causes a force to be exerted on the fluid, and, as a result, the fluid flows. Cage (8) and Brill (6) discuss the operation and types of electromagnetic pumps.

Special Pumps. Turbine pumps are also called periphery, turbulent, friction, and regenerative pumps (26). A turbine pump has a rotating impeller, which has numerous vanes and relatively close clearances to the covering case. Flow around the vanes is restricted because of the close tolerances, and the rapidly rotating vanes cause pressure increases of the fluid inside the pump. Iverson (26) has studied these pumps, and he reports on the design factors which affect their operation. The capacity is proportional to the speed, the head proportional to the speed squared, and the power proportional to the speed cubed.

A spindle drag pump was developed by Strub (59). It is based on the theory of a screw extruder. Viscous liquids have been pumped to pressures of 10,000–30,000 p.s.i. Apparently only small pumps have been built so far, but it appears that moderate size pumps could be designed. Rosen (48) reports on a pump useful for pumping highly corrosive fluids. The piston movement in the pump is caused by a magnetic field. Fluorine and hydrogen fluoride have been pumped successfully. The Milton Roy Company (38) has announced operating characteristics of a positive displacement pump which operates through one cycle for each electrical impulse delivered to a solenoid-operated clutch.

The Western Machinery Company (66) now offers a new pump for handling slurries, pulps, etc. Power is transmitted to the fluid exactly as in a fluid-type torque converter. A recessed impeller creates a vortex effect in the fluid in the main pump body. As a result, the suction and pressure head necessary for pumping are developed.

Pumps for non-Newtonian liquids must be chosen with care (2). A centrifugal pump is generally satisfactory for Bingham-plastic, pseudoplastic, and thixotropic materials. Open impellers should be employed where the particles would tend to plug the small passages in a closed impeller. A centrifugal pump will sometimes reduce the viscosity of the fluid so much that a degradation and dispersion of the particles in the fluid will occur. In these cases a diaphragm or piston pump may be preferred. Rotary gear pumps can be used for solutions but not suspensions. When dilatant materials are pumped, a diaphragm, piston, or screw pump is often used.

Pump Operation and Maintenance. When a pump is operating at high rates, local pressures in the inlet liquid may fall below the vapor pressure of the liquid. Vaporization will occur at these points, and the bubbles which are formed will collapse violently when they reach the regions of higher pressures or lower velocities. This phenomenon is called cavitation and is highly undesirable since it reduces pump capacity and tends physically to damage and erode the pump. Recent studies (3, 18, 22, 25) have been made on various aspects of the problem. Most cavitation can be prevented if the net positive suction head (NPSH) is increased somewhat. Inlet lines to the pump are sometimes too small and hence reduce the NPSH. Iverson (25) has shown that a vortex formation may be associated with cavitation. When deep-well turbine or propeller pumps are used, vortex formation will sometimes cause air entrainment, which is also highly undesirable. Model studies will in some cases give sufficient data for design purposes.

The Worthington Corporation (69) has recently published a list of items to check for steam-pump trouble shooters. Their list should be of value to pump operators and supervisors. Allison and Walmsley (1) have listed factors to be determined in a turn-around pump inspection. The pump deterioration such as mechanical wear, corrosiion, erosion, and improper wear should be evaluated. Relatively frequent inspections are desirable since more continuous operation and better efficiency will be obtained. A complete record should be maintained of each pump. The Sun Oil Company recently announced (67) the results of their preventive maintenance study. They found that a regular schedule for an internal inspection of their pumps was desirable. Pump replacement is always an important consideration. Calculations of the power cost savings and the capitalization amounts can be quickly calculated by use of a chart prepared by Cromwell (13).

Gas Pumps and Compressors

Reciprocating Compressors. Reciprocating compressors are divided by Murphy (42) into three classes: light, intermittent-duty; heavy industrial, medium-duty; and large, heavy-duty units. The selection of a compressor for a given job is facilitated by classifying compressors in this manner. Murphy discusses the factors to be considered, including cooling, for compressors. Several new methods for compressor maintenance are reported by Ridgway (51). Techniques of resleeving the cylinders; metal-spray reconditioning of rods, pistons, and cylinders; and chrome-plating cylinder walls have been developed and successfully tested. Ridgway indicates that good technicians should always be employed for reconditioning compressors.

Centrifugal, Axial, and Centripetal Compressors. Centrifugal and axial compressors have been developed that will compress large quantities of gas up to pressures of several thousand pounds p.s.i. Lowell (35) has compared these two types of compressors. Centrifugal compressors are machines in which a velocity and pressure are imparted to a gas in a radial direction by one or more impeller-diffuser combinations. Axial compressors however impart velocity and pressure to gases in an axial direction by means of moving and stationary blades. Centrifugal compressors are essentially variable-capacity, constant-pressure machines. The axial compressor has however more uniform capacity, more variable pressure, and better efficiencies. Generally centrifugal compressors are used for medium capacities and axial compressors for high capacities. Compressors are often built with several stages in order to obtain higher gas pressures. As a rule of thumb, axial compressors require twice as many stages as a comparable centrifugal compressor for the same pressure rating. The efficiencies of a single-stage centrifugal compressor are generally about 50% (16). The overall efficiency decreases as the number of stages increase and for an eight-stage centrifugal compressor is about 25%. The efficiencies of axial compressors depend on the rotative speed and the Reynolds number (45). Basic efficiencies of a two-stage axial compressor were found to vary between 83 and 86% at a Reynolds number of 450,000 and between 67 and 81% at a Reynolds number of 50,000.

Several recent papers have discussed various aspects of centrifugal compressors. These include discussion of the principles and theory of operation (16, 35), performance characteristics (32, 57), process and mechanical design (54), selection of compressors (31, 55), operation and maintenance (10), and seals for compressors (12). These papers are recommended to the engineer interested in compressors.

Radial inward-flow (centripetal) turbines have several advantages over axial-flow turbines. The advantages are listed by Birmann (4), who thinks the greatest merit of the centripetal turbine is the fact that it can be designed for specific outputs far exceeding those of the axial compressor. He presents drawings, photographs, test results, and numerical examples to prove this superiority. Centripetal compressors have been used to compress steam and exhaust gases from cars and airplanes.

Blowers and Fans. Blowers have been defined as dynamic-type machines which compress gases up to 40 p.s.i. (35). Maintenance costs of blowers are discussed by Hylton (24). Costs, as might be expected, depend on the selection, installation, and start-up of the blower. It has been found that regular inspections of the blowers will often reduce maintenance costs. Rostafinski (49) has found that atmospheric changes often affect the operation of air blowers of the centrifugal-compressor type. Changes of the humidity and temperature of the air affect the capacity of the blower. Gutzwiller (20) reports that the correct design, proper installation, and adequate maintenance of cooling tower fans and gear drives will save money. He makes several suggestions for these fans and auxiliary equipment.

Vacuum Pumps. The operation and design of high-vacuum systems are discussed by Stoddard and Mooz (58). They report on their observations and experiences with mechanical and diffusion pumps and with auxiliary equipment for the pumps. Lawrence (33) presents several graphs which he has found useful for selecting a vapor pump (diffusion pump). Factors which he considers important include lowest obtainable pressure, volumetric speed as a function of the inlet pressure or of throughput, throughput limitations at high inlet pressures, and maximum allowable forepressures. The characteristics of vapor diffusion pumps have also been reported by Mukherjee (40) and Riddiford and Coe (50). Their papers should be of assistance in designing such a pump.

Gas Jet Compressors. Gas jet compressors are simple devices with no moving parts. The low-pressure gas is entrained by a stream of gas flowing at high velocities. Although these compressors have low efficiencies, they find widespread use for compressing gases and for obtaining vacuums. The design and operation of gas jet compressors were studied by Dotterweich and Mooney (15) and Fletcher (17). They present numerous graphs which should be useful for design purposes. In addition, they discuss the selection of these compressors. Jackson (28) reports on corrosion problems in the compressors. New alloys and plastics, such as Teflon, are finding uses in the apparatus, especially in the throats and nozzles. Lead and carbon liners are also provided in some cases.

Maintenance and Miscellaneous. Various compressor operating problems are outlined by Murphy (44). Problems considered include piping size of inlet and outlet lines, air leaks, low air pressure, and start-up procedures. The design of auxiliary equipment for compressors plays a vital role in compressor efficiencies (43). Careful design of filters, after-coolers, cooling water piping, and piping are important. Preventive maintenance starts with the compressor design and follows through the installation and operation (30). Factors to be considered in regular inspections of a compressor are outlined.

Ghormley (19) reports on the selection of an unloading compressor. Such a compressor provides a gas pressure above a liquid so that the liquid will tend to flow from the container due to the increased pressure.

Conclusions

Many new developments in pumping and compressing have recently been reported. The new equipment and theories reported will probably find frequent uses in the oil processing and chemical industries. The result will be lower pumping costs and better service.

REFERENCES

1. Allison, W. D., and Walmsley, J. G., Pet. Refiner, *34* (3), 160 (1955).
2. Alves, G. E., Boucher, D. F., and Pigford, R. L., Chem. Eng. Prog., *48*, 385 (1952).
3. Balhan, J., Ingenier, *65*, No. 6:W29 (Feb. 6, 1953); No. 7:W41 (Feb. 13, 1953).
4. Birmann, R., Trans. Am. Soc. Mech. Engr., *76*, 173 (1954).
5. Brand, D. C., Chem. Eng. Prog., *52*, 130 (1956).
6. Brill, E. F., Mech. Eng., *75*, 369 (1953).
7. Brown, G. G., and co-authors, "Unit Operations," John Wiley and Sons Inc., New York (1950).
8. Cage, J. F. Jr., Mech. Eng., *75*, 467 (1953).
9. Clark, P. M., Mech. Eng., *75*, 615 (1953).
10. Cole, S. L., and Peet, G. D., Petroleum Refiner, *34* (1), 140 (1955).
11. Coopey, W., Pet. Refiner, *33* (12), 233 (1954).
12. Crego, D. F., Pet. Refiner, *34* (1), 143 (1956).
13. Cromwell, C. E., Pet. Refiner, *33* (9), 300 (1954).
14. Cygan, R., and Stelle, A. M., Chem. Eng. Prog., *52*, 157 (1956).
15. Dotterweich, F. H., and Mooney, C. V., Pet. Refiner, *34* (10), 104 (1955).
16. Erb, H. A., Pet. Refiner, *34* (1), 123 (1955).
17. Fletcher, G. R., Pet. Refiner, *33* (2), 107 (1954).
18. Garnar, L. H., Pet. Refiner, *33* (8), 117 (1954).
19. Ghormley, E. L., Pet. Refiner, *35* (5), 211 (1956).
20. Gutswiller, J. E., Pet. Refiner, *35* (3), 189 (1956).
21. Hiteshue, R. W., and Clark, E. L., Mech. Eng., *75*, 205 (1953).
22. Huppert, M. C., and Benser, W. A., J. Aero. Sci., 20, 835 (1953).
23. Hutton, S. P., Engr. Digest, *15*, 121 (March 1954).
24. Hylton, J. L., Pet. Refiner, *35* (1), 136 (1956).
25. Iverson, H. W., Trans. Am. Soc. Mech. Eng., *75*, 635 (1953).
26. Iverson, H. W., Trans. Am. Soc. Mech. Eng., *77*, 19 (1955).
27. Jack, R. L., Chem. Eng. Prog., *49*, 235 (1953).
28. Jackson, D. H., Chem. Eng. Prog., *49*, 102 (1953).
29. Jones, D. H., Trans. Am. Soc. Mech. Eng., *75*, 361 (1953).
30. Julian, J. J., and Schaefer, R. A., Pet. Refiner, *35* (1), 129 (1956).
31. Koenig, C. F., and Holveck, L. J., Pet. Refiner, *34* (10), 110 (1955).
32. Latimer, T. P., Pet. Refiner, *34* (1), 130 (1955).
33. Lawrence, R. B., Chem. Eng. Prog., *48*, 537 (1952).
34. Litzenberg, D. P., and White, H. T., Chem. Eng. Progress, *50*, 436 (1954).
35. Lowell, W. O., Pet. Refiner, *34* (1), 118 (1955).
36. Mann, M., Pet. Refiner, *32* (10), 133 (1953).
37. Mann, M. S., Pet. Refiner, *32* (12), 111 (1953).
38. Milton Roy Company, Philadelphia, Pa., Bulletin 654 (1954).
39. Mitchell, C. J. B., Chem. Eng. Prog., *50*, 431 (1954).
40. Mukherjee, S. K., and Dutt, P. K., Indian J. Phys., *27*, 137 (March 1953).
41. Murdock, M. L., Chem. Engr. Prog., *52*, 135 (1956).
42. Murphy, L. J., Pet. Refiner, *32* (2), 115 (1953).
43. Murphy, L. J., Pet. Refiner, *32* (3), 137 (1953).
44. Murphy, L. J., Pet. Refiner, *32* (4), 173 (1953).
45. New, W. R., Redding, A. H., Saldin, H. B., and Fentress, K. O., Trans. Am. Soc. Mech. Eng., *76*, 473 (1954).
46. Norton, R. D., Chem. Eng., *62* (3), 183 (1955).
47. Perry, J. H. (editor), "Chemical Engineers' Handbook," McGraw-Hill Book Company Inc., New York (1950).
48. Rosen, F. D., Rev. Sci. Inst., *24*, 106 (1953).
49. Rostafinski, W. A., Pet. Refiner, *34* (10), 116 (1955).
50. Riddiford, L., and Coe, R. F., J. Sci. Instr., *31*, 33 (1954).
51. Ridgway, R. S., Pet. Refiner, *33* (1), 110 (1954).
52. Savage, H. W., and Cobb, W. G., Chem. Eng. Prog., *50*, 445 (1954).
53. Sheen, R. T., and Fell, A. D., Chem. Eng. Prog., *49*, 299 (1953).
54. Shields, C., Pet. Refiner, *34* (1), 132 (1955).
55. Smith, O. A., Pet. Refiner, *34* (1), 136 (1955).
56. Sniffen, T. J., Pet. Refiner, *35* (3), 207 (1956).
57. Steinbock, S. R., Pet. Refiner, *33* (2), 133 (1954).
58. Stoddard, C. K., and Mooz, W. E., Chem. Eng. Prog., *49*, 197 (1953).
59. Strub, R. A., Machine Design, *25*, 149 (July 1953).
60. Ullock, D. S., Chem. Eng. Prog., *51*, 207 (1955).
61. Ullock, D. S., Reynolds, J. A., and Hudson, T. W., Chem. Eng. Prog., *52*, 3J (1956).
62. Walmsley, J. G., and Ward, H. A. Jr., Pet. Refiner, *32* (9), 203 (1953).
63. Weintraub, M., Ind. Eng. Chem., *46*. 112 (1954).
64. Weintraub, M., Ind. Eng. Chem., *47*. 558 (1955).
65. Weintraub, M., Ind. Eng. Chem., *48*. 532 (1956).
66. Western Machinery Corp., San Francisco, Calif. Bull. PSB10 (1955).
67. Wise, W. M., Pet. Refiner, *35* (1), 121 (1956).
68. Wise, W. M., Chem. Eng. Prog., *51* (8), 38 (1955).
69. Wise, W. M., Pet. Refiner, *35* (6), 140 (1956).