Equipment for an Alkylation Plant for Production of High-Octane Gasoline

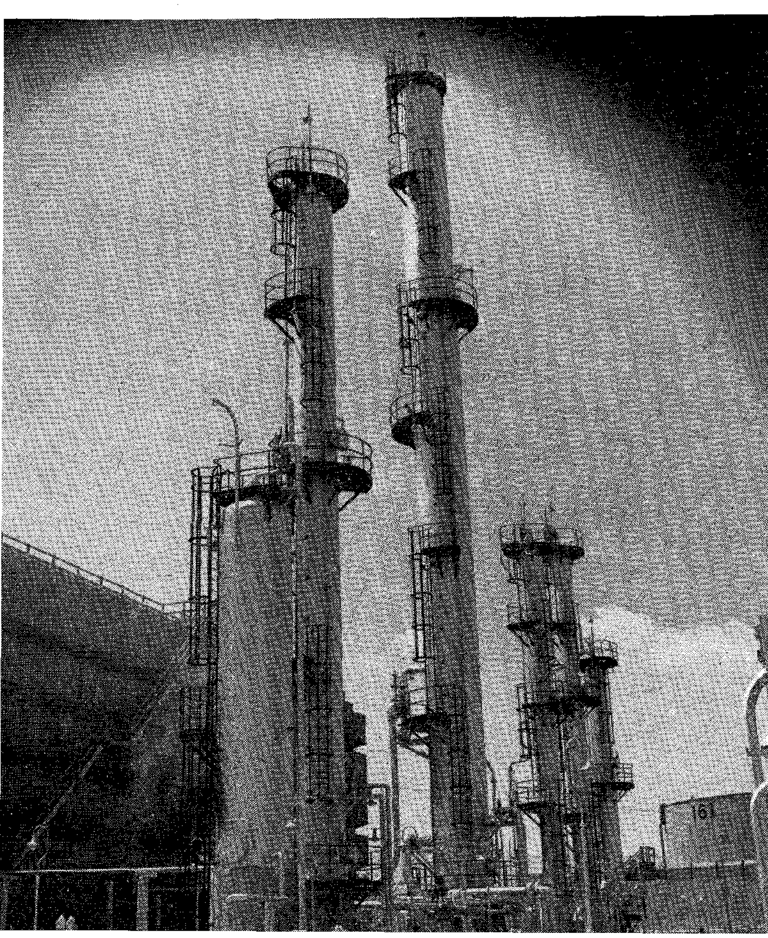
BY FRITZ KARGE

THE multiplication of the country's fighting, bombing and transporting airplanes has brought with it a greatly increased demand for the best gasoline that can be produced at a reasonable cost. For the time being, a gasoline of 100 octane rating complies with this requirement. Such a gasoline gives to the planes better performance, particularly at high altitudes, and more power and speed with lighter engines than a good grade of motor gasoline of 70 octane rating. It has been predicted that in the future airplane fuels of 120 to 130 octane rating will be demanded and made available. As a matter of fact, such gasolines can now be, and have been, produced. We can speak of a better than 100 rating since this arbitrary standard was established when it seemed the ultimate goal.

Several processes have been developed during the last five or six years, the end product of which is either a 100 octane gasoline or one of a somewhat lower rating, and many plants have been built during the last two years and many others are in the course of construction, all for the production of aviation gasoline. Most of them use the alkylation method.

ALKYLATION

Alkylation is a process by which, through the action of a catalyst, iso-butane, a saturated branched-chain hydrocarbon is combined with a low boiling point olefin, an unsaturated branch or straight chain hydrocarbon, to form a heavier saturated branched-chain hydrocarbon.



The hydrocarbon, so produced, makes an excellent aviation fuel when blended with certain other hydrocarbons to the desired volatility characteristics. It has an octane rating of at least 93. It is highly susceptible to lead, so that only small additions of tetraethyl lead raise its octane rating to 100. It has a very low sulphur content, a high calorific value and it is not very sensitive to different engine conditions.

The catalyst employed in most alkylation plants is a 96 to 100 per cent sulphuric acid. Hydrofluoric acid is also used and other catalysts might be introduced as time goes on.

It is one of the romantic achievements of the petroleum industry that this almost ideal aviation fuel is produced out of charging stocks that a few years ago were considered a nuisance because of their high volatility, making them unfit for use in motor fuel.

THE PROCESS

The purpose of this article is briefly to outline the equipment and apparatus for an alkylation plant, using sulphuric acid as a catalyst. It is beyond the scope of the article to give detailed information of the process itself. It will be necessary, however, to allude to steps in the process in order to explain the purpose of various equipment items. It is intendedly not a reference paper to serve as a basis on which such a plant might be designed.

A plant will be chosen producing from 2500 to 3000 barrels of alkylate per 24-hour day, giving, after blending with an equal volume of other hydrocarbons, from 210,000 to 250,000 gallons of aviation gasoline, enough for approximately an equal number of air miles for all but the most powerful planes. It is assumed that the raw materials, butane, iso-butane, and butene, are available from a catalytic petroleum cracking plant, already in existence or under construction. These cracking plants, many of which have been built, can produce large quantities of the hydrocarbons necessary for the alkylation process without lowering the quality of the motor gasoline or heavier fractions which they produce. The crude oil and natural gas that flow from the wells with the oil contain no olefins. The olefins for alkylation must be made by a cracking process.

The charging stocks for an alkylation plant are not usually produced in pure form. Other hydrocarbons are admixed. They must be removed before alkylation since they affect the desired reaction adversely and cause a greater acid consumption. To purify the raw stock by the removal of all undesirable admixtures requires often as much equipment as the alkylation process itself.

Iso-butane is seldom available in large enough quantities, but butane is. To change this straight chain hydrocarbon to the branched-chain fraction of the same number of carbon and hydrogen atoms an isomerization plant often becomes one of the parts of an alkylation plant and special equipment is required. The alkylate itself must be finally purified, the catalytic treatment leaving varying amounts of uncombined raw stocks in the alkylate.

The reaction with the sulphuric acid is most economical when the iso-butane-butene ratio is held at about five to one. Approximately four parts of the iso-butane appears then uncombined in the alkylate and must be removed, again to enter the feed stream. This also requires equipment. Finally a small amount of acid is carried over from the reaction, which must be eliminated by a neutralizing caustic wash.

The equipment in most alkylation plants divides itself therefore roughly into the following categories: Equipment for purifying the feed stock; alkylation reaction equipment and equipment for purifying the alkylate. A brief description of the various equipment items must suffice.

PURIFICATION

For the removal of undesired hydrocarbon fractions before and after alkylation, towers, or bubble columns, as they are often called, are employed. They are cylindrical vertical steel vessels of a variety of dimensions. Here might be a number of small towers, three feet in diameter and 30 to 100 feet high; there others six to eight feet in diameter and 30 to 80 feet high. Usually a larger tower, nine to 10 feet in diameter and 140 to 160 feet high, is required to remove the uncombined iso-butane from the norma-butane and alkylate.

In simple words, these towers effect an intimate contact between a hydrocarbon vapor and a hydrocarbon liquid and a separation due to differences in boiling points. The vapor rises upwards, the liquid trickles downwards. The contact is brought about by horizontal shelves or trays and an arrangement on them of holes, chimneys, bubble caps, weirs and downcomers, by means of which the vapor is forced to bubble through the liquid. The size of the towers, number of trays, operating pressures and temperatures depend upon the desired interaction of vapor and liquid and upon the character of the stocks acting upon each other. In the interaction of vapor and liquid under controlled temperature and pressure conditions vapor fractions are absorbed by the liquid or liquid fractions are liberated to the vapor.

CATALYSIS

The mixing of the sulphuric acid with the hydrocarbon, approximately in equal proportions, is carried on continuously in so-called contactors, the design of which varies for different users. One type is provided with a mixing impeller rotated by steam turbines or electric motors. The contactor is a vertical vessel and a tube bundle extends through its interior except for the space housing the impeller and certain passages for the liquid. The impeller circulates the mixture at the high rate of about 50,000 gallons per minute. The catalytic reaction has been found to take place most economically at a temperature of from 28 degrees to 50 degrees F., considerably below ordinary atmospheric temperatures. A cooling medium, usually ammonia, is therefore circulated through the tube bundle to remove the heat of reaction and mixing in the contactors, after pre-cooling the hydrocarbon in an ammonia chiller. Refrigeration equipment is therefore needed. For a plant of 2500 barrels of alkylate per day a daily refrigerant capacity of about 750 tons is sufficient. Whether to employ the ammonia compressor or ammonia absorption process depends largely upon the relative availability and cost of electric power and steam, the compressor process calling for more electric power but less steam.

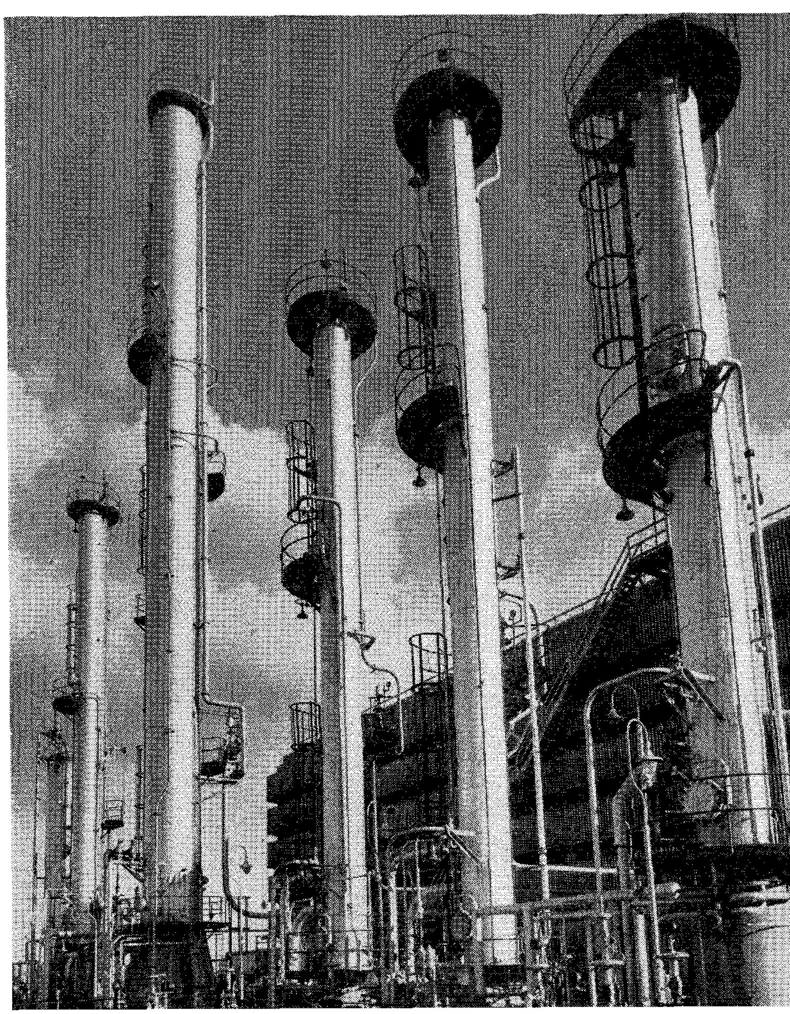
The stream of the sulphuric acid-hydrocarbon mixture from the contactors is directed to acid settlers, horizontal vessels equipped with partial trays. The separation takes place because of the much higher specific gravity of the acid.

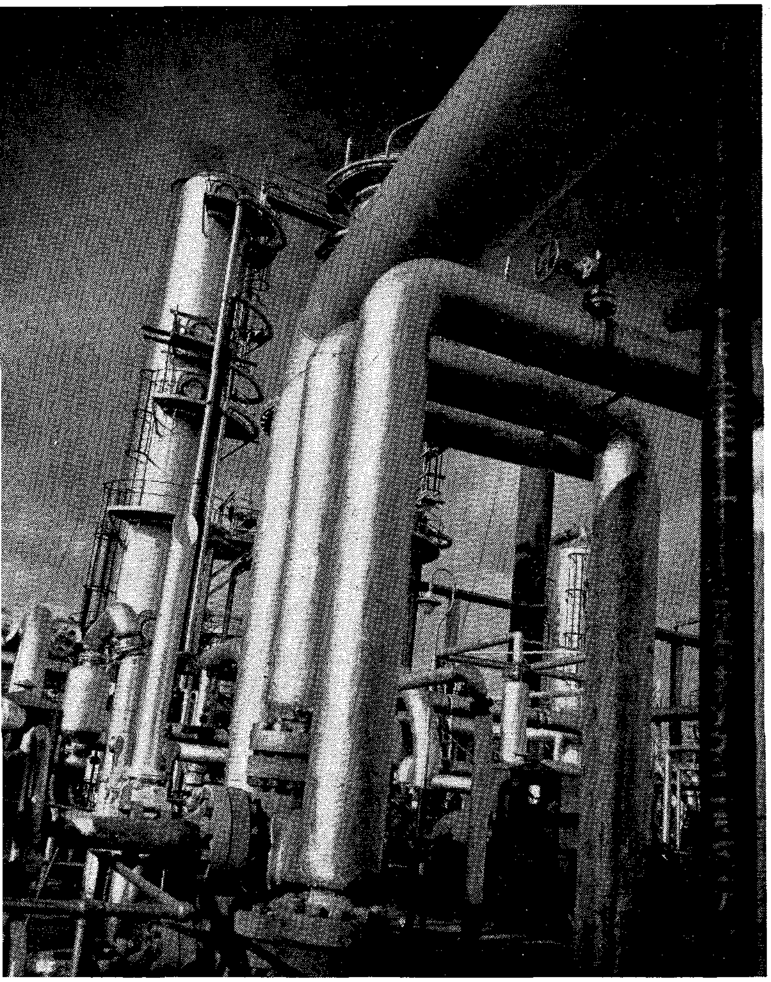
The isomerization process through which butane atoms are rearranged to form iso-butane usually employs anhydrous hydrogen chloride as an activator for a catalyst, and special equipment must be provided.

As pointed out, all reactions must be brought about at certain temperatures, depending upon the reactions desired and the reacting materials. In their course of travel through the plant the liquids must be heated perhaps several times, to reacting or vaporizing temperatures, steam being largely employed as the heating medium. The vapors must be cooled to condensation, water serving as cooling medium. Wherever possible, however, hot liquids that must be cooled are made to give up heat to colder liquids in need of heating, through the use of tube interchangers. Similar shell-tube equipment is provided for heating, vaporizing, cooling and condensing.

Storage tanks are required for the charging stocks, for some intermediate cuts and for the finished product. Pressure tanks in the shape of spheroids of appropriate capacity are often provided for the charging stocks in order to prevent evaporation. A number of accumulator tanks, horizontal or vertical steel vessels of sufficient volumetric and pressure capacity, must be installed to hold the liquid hydrocarbons in their various stages.

Pumps are needed for handling the various liquids in their progressive flow through the plant. Many centrifu-





gal pumps are used whenever the flow rate and differential pressure conditions suit their basic hydraulic characteristics. For small pumping rates with high-pressure differentials reciprocating steam simplex pumps offer the best service. For the acid, rotary pumps are often chosen. Cooling water is efficiently handled by centrifugal pumps. Whether to drive the centrifugal and rotary pumps by electric motors or by steam turbines depends largely upon the availability and relative cost of these media, and the need for low pressure exhaust steam in other parts of the refinery. In many plants electric motors are installed as operating prime movers, and steam turbines are provided for standby pumps, to be used in case of failure of the electric power supply, and when a pump requires overhauling or repacking.

Large quantities of cooling water must be supplied, requiring usually a cooling tower for atmospheric or for forced draft cooling, with the necessary pumps. An alkylation plant of the size mentioned will need approximately 10,000 gallons per minute of cooling water. The choice of the tower will be determined largely by the prevailing minimum and maximum atmospheric temperature conditions.

PIPING

Interconnecting pipe lines for hydrocarbon liquids and vapors, for steam, condensate, water, catalysts, compressed air, and waste materials constitute one of the principal equipment items of the plant. In size they might vary from tubes of one-quarter-inch diameter for instrument air to others of 24-inch diameter for cooling water, some operating by gravity, others under 500 to 600 pounds per square inch, the majority between these extremes.

Steel is the pipe material used most. Copper tubing, because of its greater flexibility and corrosion resistance, handles air to control instruments. Short runs of stainless steel tubing are employed in the hydrogenchloride circuit. For large cooling water lines transite pressure pipe has found favor during the last few years. Seamless pipe is often specified for hydrocarbon and high pressure steam lines. For other services lapwelded or continuous electric weld pipe meets the requirements. Many varieties of shut-off and control devices, carefully chosen for the service, must be provided to block the flow to and from tanks, accumulators, towers, heating and cooling equipment; to connect the pumps to the maze of hydrocarbon pipe lines and to the live and exhaust steam mains, and to make possible the shunting of streams to the various units of the plant. Gate valves, check valves, globe valves, needle valves and lubricated plug cocks must be located according to services required. All such fittings over two inches in size are usually flanged, those of smaller sizes screwed.

Desuperheaters might be considered another type of equipment belonging to the piping system. Since superheated steam is not an efficient heating medium, they are installed in heating-steam lines wherever they take off lines carrying superheated steam to prime movers. Condensate pots, steam traps, and drums in which high-pressure condensate is partially flashed into lower pressure steam are also parts of the piping system, as well as separators, ejectors, and exhaust heads.

A sewer system covers all parts of the plant to carry away any hydrocarbon leaks, condensate drips, water for washing floors, etc. In buildings cast iron pipe is used, often with lead joints; outside of buildings, vitrified clay pipe with cement joints, and with acid proof joints below the highest point at which acid drips might originate. The sewer usually leads to a separator where the water is freed of hydrocarbons and acid.

INSTRUMENTS

It has been said truly that a modern refinery could not be operated efficiently and economically without automatic control and recording devices. Flow rates, temperatures and pressures must be maintained continuously and with very small variations at so many points in a plant that only an army of men could do the work, and not very well at that. The many kinds of instruments, developed as demand arose, are insensible to moods, fits of inattentiveness, varying weather conditions, and other factors influencing the constancy of application that would be required of human beings. Instruments make it possible to operate so large and intricate a refinery plant with only three or four men on a shift and always to have a complete and faithful performance record available.

A list of the more important of such devices reads something like this: Flow and liquid level controllers, indicators and recorders, gage glasses, pressure gages, recorders and controllers, back-pressure controllers, and temperature recorders and controllers. Temperatures can be determined in any necessary part of any equipment through the installation of thermocouples, the lead wires of which end in a single panel of the instrument board. Thermometers, installed in wells, give local temperatures. Pressure relief valves are employed to safeguard the equipment against overpressures. All but the locally mounted instruments have their indicating and recording parts installed on an instrument board, often centrally located near the pumps. The board in the plant under

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sponsibility and must apply a good share of its attention to the task, just as it does to any other undertaking of vital importance. Every kind of work that men do involves some degree of hazard, and every uncontrolled hazard, if given enough time, will produce its share of injuries. But proper attention to safety will result in the elimination of almost all the injuries that would otherwise occur, regardless of the industry, the type of operation, or the occupation in question. In management is vested all authority, the determination of policies and executive direction; from management must come the drive for safety. Management must want to eliminate injuries badly enough to make accident prevention a vital part of all activities. Prevention must be given continuous attention along with such matters as cost, quality, and production.

Perhaps in time of peace you may treat with accidents as you please, particularly if you are willing to pay the bill. But in time of war, it is your patriotic duty to conserve the only resource for which no substitute can be found—the number one raw material of war—MAN-POWER.

Modern Construction in Turkey

(*Continued from Page* 4)

and supplies, asphaltic membranes and hardware (with the exception of nails) are imported from foreign countries.

Labor is cheap compared to material cost. Unskilled labor is abundant and the wages are low. A pick-and-shovel workman, for example, normally earns 60 to 90 cents for an eight-hour day. Of course, one should consider that it is possible for this type of a workman to feed himself for 40 cents a day, but even then his financial life is very modest. Skilled labor is somewhat better off; a carpenter earns from two to four dollars a day. The big jump comes in the earnings of the professional class, such as the engineers and architects. This is primarily due to the great need for such services, and the civil engineer or architect enjoys a distinct position in income and prestige. Strikes and labor disputes of major proportions are practically nonexistent in Turkey. Problems that arise between the workmen and the employer are referred to the "labor inspectors," who see to it that such problems are settled according to the laws and regulations of the republic.

As a result of low labor rates the cost of construction in Turkey is below what it is in the United States. Apartment houses cost from two to three dollars per square foot and the very modern public buildings that are being erected feverishly at the present time cost from four to eight dollars per square foot. The labor cost in the big items such as reinforced concrete, brick masonry, plaster, etc., is about 15 per cent of the material cost. The contractors are naturally very sensitive about any kind of material waste.

Bids for government construction follow a method which has proved successful in this period of intensified construction. The architectural plans are prepared by government offices and a rough material estimate of the future building is made. Then the job is let out for bids. Each bidder receives a set of design, material and workmanship specifications, along with the general architectural drawings. The designing offices of the participating contractors use their own judgment and skill in producing the structural design. The contractors each submit a bid which is based on unit prices. These unit prices when multiplied by the material quantities add up to the total price of the bid. The advantage of this method is that it stimulates the contractors to prepare a design that will be of minimum total cost. As a result of this system the contractors are very conscious of the value of a skillful structural engineer.

LESS LABOR-SAVING EQUIPMENT

Labor-saving mechanical equipment for construction is not used as much as in this country. Concrete mixers and material elevators are usually the only mechanical equipment used in the field. Vibrators, for example, are not used, because it is cheaper to tamp the fresh concrete by hand tools, and the forms are not built sturdily enough to withstand the vibration. Two-inch boards are used under beams and one-inch planks are used for slabs and for sides of beams. All attachment of forms is done by nails.

The building code for reinforced concrete calls for all bars to be provided with hooks. Since plain bars are used exclusively and earthquake forces are expected, this is an inexpensive security measure. As in most European codes the value of shear strength of concrete is neglected once the shear intensity exceeds 40 pounds per square inch. The allowable fiber stresses in concrete are about 25 per cent lower than the values generally used in the United States for ordinary construction. Up to recent years moment factors were used, or, for more exact analysis, the "three-moment equation"; however, the Hardy Cross method of determining moments is becoming more and more popular at the present.

Due to the great demand for technically trained men the government has adopted a very benevolent attitude in employing foreign engineers and architects, and most of these men have done splendid jobs. The foreign engineer, however, has a few problems to consider before making his luxurious salary. The tax rate starts at about 30 per cent withholding and increases as the income gets larger. When leaving the country a person is allowed to take out only one-third of the cash he has made. However, judging by the fact that there are a large number of foreign engineers in the country, these restrictions apparently are not too severe.

The photographs displayed with this article were taken in 1939, and show features of design and construction of the Graduate School of History, Language and Geography, located at Ankara. The author worked on the structural design of this project and was present during the entire period of construction.

Alkylation Plant

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review might be 45 feet long, eight feet high, with possibly three horizontal tiers of dials of various sizes and shapes. At any moment a glance will show what any unit of the equipment, provided with an instrument connection, is doing.

Electric power and light installations in an alkylation plant are extensive. Explosion-proof motors are used in all areas considered hazardous because of the possible presence of hydrocarbon vapors. They might vary in size from 1/4 horsepower for driving an exhaust fan to 450 horsepower for furnishing the motive power for a large water pump, synchronous motors being preferred for such units. Electric current is usually brought in several appropriate voltages to a main switchroom, from which it is distributed through panel boards to its many purposes. Good lighting must be provided for all equipment, and to the top of even the tallest bubble column. Many of the instruments contain electric devices. In many plants a turbogenerator is installed to start automatically in case of power failure and to maintain at least the minimum light throughout the plant necessary for operation. The instruments are also connected to this emergency power supply.

BUILDINGS

In California it has been found entirely satisfactory to have most equipment, including pumps, in the open. In more inclement climates, however, housing requires a considerable outlay, particularly when the atmospheric temperature hovers below zero for months and is accompanied by heavy snowfalls. Steel frame, corrugated iron covered buildings serve in many locations. For colder regions, reinforced concrete frames with brick walls are often used.

Unit steam heaters or radiators are provided to maintain temperatures in the buildings safely above freezing, and exhaust fans are installed in the walls a short distance above the floor to remove hydrocarbon vapors, all of which are heavier than air. Steel windows and doors are preferred for such substantial buildings. The pipelines of many sizes and purposes are supported from the beams of the floor above, and others are brought to the pumps in trenches, sunk below the floor, covered with steel plates or gratings and connected to the sewer.

Compressed air must be available for instruments, dried in special vessels, when the climate is such that moist air might freeze in small air lines, for the blowing of sulphuric acid from vessel to vessel and for other purposes. Air compressors with accumulators must therefore be provided.

Heavy and tall structural steel supports are needed for certain portions of the refrigeration equipment, for the contactors, and for the reactors in the isomerization plant. All bubble towers must be made accessible throughout their height by means of steel ladders and platforms. Operating walkways over some of the horizontal vessels add to the use of structural steel.

In order to conserve heat and to better maintain the necessary operating temperatures, many bubble columns, heaters, turbines, pipelines and other units of the equipment are insulated. Cold insulation is required on all equipment operating at lower than atmospheric temperature.

COOPERATION

It should be pointed out that no two plants of the same size will require identical equipment. The exact composition and purity of the charging stocks determine the operating cycle and equipment. The type of foundation, the type of building construction, the type of power source to be employed will depend upon the local conditions prevailing at the plant site.

The construction and the assembly of the equipment for a plant to accomplish these operations is a challenging undertaking. Laying the plans and putting them into operation requires the cooperative effort of chemical, mechanical, civil, electrical, construction and metallurgical engineers, as well as purchasing personnel. This is typical of an extensive engineering job involving diversified activities.

C. I. T. NEWS

IN PRAISE OF TRUSTEES

By ROBERT A. MILLIKAN

On January 24 a dinner was held at the California Club to honor James R. Page, recently elected President of the Board of Trustees of the California Institute of Techonology. Dr. Millikan's remarks at that dinner are presented here because it is believed that the readers of ENGINEERING AND SCIENCE will be interested in the part a Board of Trustees is playing in the operation of one type of war industry.—Editor.

YOUR HOSTS are the Trustees and I am sure you want to know what manner of job they do. Being very modest men they will not tell you, but I have insisted on being given a few minutes to do so, for I am not on the Board and I can properly speak "In Praise of the Trustees."

The fact that they have always maintained the policy that no salaried employee can be a board member, or indeed have a vote on its finance committee, reveals in itself the seriousness and the long-range wisdom with which they take their job in the rendering of a wholly free public service to the community and the nation.

Let me first say something in general about the genus "Board of Trustees," for our higher educational system in the United States consists of much more than a thousand of these privately supported colleges and universities all over this land created wholly by private initiative and controlled entirely by Boards of Trustees operating under charters granted by 48 states. Here is the free democratic American way of life at its best—free from all possibility of political influences. It is the finest expression of the free-enterprise system here consisting in the self-education of each community in the finding and meeting of its own educational needs, the most fundamental of its needs. Add to these private institutions the much smaller number of our tax-supported institutions created by the communities of 48 different states—it is in the number of these states that freedom's safety lies—and there has still been maintained the principle of local self-government in our higher educational system. This is the cornerstone of the freedom which we are fighting this great war to preserve.

With any centralized system of education such as is characteristic of all totalitarian states, it is inevitable, as the recent history of the world amply demonstrates, that education becomes replaced by indoctrination in the interests of the perpetuation of the power of the group in control of government, and freedom is destroyed at its source.