section of the main CO boiler feedwater heater and is pumped by turbine-driven desuperheating pumps to the desuperheating stations. These turbine-driven pumps are controlled automatically from the main control board and can be taken in or out of service from the main control board. In the event that these desuperheating pumps fail, desuperheating water can be taken from the main boiler feed pumps for the CO boiler. This is done automatically by an automatic cut-in valve when the desuperheating water pressure falls below a set pressure. Only in an extreme emergency will boiler feedwater be used for desuperheating because the soluble salts in the boiler feedwater would foul the superheater.

**Operations to Date**

Table 3 gives the results of actual field tests. It is noted that a transfer rate of approximately 70 was obtained. The design was based on a transfer rate of 67.5. It is noted from the table that the maximum heat absorbed to date was approximately 169,000,000 Btu per hr. The amount of heat required to superheat the steam produced from the CO boiler to 750 F would be approximately 80,000,000 Btu per hr. Therefore the heat absorbed by the respray steam superheater will vary between approximately 80,000,000 Btu per hr and 170,000,000 Btu per hr. It will depend upon the amount of heat that is required to be extracted from the regenerator bed to hold the regenerator-bed temperature at its desired level. The operations to date have been better than expected. The CO boiler produces steam at approximately 80,000,000 Btu per hr. Therefore the heat of burning of the CO gas. This paper casts a different light on the economics of this procedure.

### Table 3 Fluidized-Bed Respray Steam Superheater Test Data

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Steam to Superheater</th>
<th>Respray Condensate to Superheater</th>
<th>Superheated Steam</th>
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<td>Pressure, psig</td>
<td>Temperature, deg F</td>
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**Conclusions**

The installation of the combination CO boiler and respray steam superheater is the natural outgrowth of Sinclair's general policy to operate fluid units on a nonheat-balance basis and conservation of fuel and electric energy. This combination allows for maximum flexibility of operation of a fluid unit to produce more and better products and, at the same time, provides maximum conservation of fuel.

In addition to the foregoing, there are several other advantages such as the following:

1. Being independent from outside sources of steam and energy during operation, shutdown, or start-up.
2. Complete control of steam production for the fluid unit under the supervision of the fluid operators.
3. Steam can be produced at high pressure and temperature which decreases the steam requirements per horsepower for fluid unit prime movers.
4. Prevents the CO gas from escaping and possible pollution of the atmosphere.
5. Precludes the possibility of unburned hydrocarbons or malodorous gases, or other gases that may cause air pollution, from escaping to the atmosphere.
7. Produces excess steam for other refinery uses and reduces the output of the refinery-fired boilers.
8. Eliminates the necessity of an added fired boiler to start up and shut down the fluid unit.
9. The cost of the CO boiler and its appurtenances is no greater than a fired boiler of equivalent output.

Successful operations of the CO boiler and the respray steam superheater have been extremely gratifying experiences which are typical of progress in a competitive industry. Competition requires maximum product quality and quantity with minimum operating expense. The CO boiler, to minimize fuel consumption by utilizing waste heat, and the respray-steam-superheater coils, to provide optimum catalytic cracking, are new tools to meet these goals.

### Acknowledgment

The authors acknowledge the following engineers for their assistance in original design, drawings, photographs, construction, and operation of the CO boiler and the respray steam superheater: C. F. Braun & Company, H. S. Spaulding, J. Bowen and M. Bason; The Babcock & Wilcox Company, F. S. Nolte, C. L. Marquez, E. H. Manny, E. Durham, L. W. Hayward, J. Knockeldorf, and L. G. Troutman; Sinclair Refining Company, W. S. Gullette, H. C. Kuhn, W. H. Decker, D. S. Stewart, R. M. Cooper, R. Y. Rankin, and W. F. Shippani.

### Discussion

D. S. Frank. The authors are to be congratulated on their very fine paper and their company is to be commended for the first installation ever to be made.

As pointed out in the paper, the data are for a nonheat-balance type unit and this discussion will be confined to the possible installation of a CO boiler on a heat-balance-type unit. The use of a heat-balance-type fluid unit versus the nonheat-balance-type unit is determined primarily on the basis of unit flexibility. In the heat-balance-type unit the heat liberated from the burning of the coke on the catalyst is used to preheat the incoming feed and supply all heat necessary for the cracking reaction. This calls for a high circulation of catalyst in order to heat the feed entering the reactor to cracking conditions. As the name implies, no outside source of heat is required. In the nonheat-balance-type unit a furnace is required to preheat the charge to the desired temperature and supplemental heat is furnished by the smaller amount of catalyst circulation.

We operate four fluid-cracking units of the heat-balance type using synthetic catalyst and one nonheat-balance-design unit using natural catalyst. In most cases we use steam generators which utilize the sensible heat from the flue gas leaving the regenerators. No effort in the past has been made to recover the heat of burning of the CO gas. This paper casts a different light on the economics of this procedure.

On a unit of 20,000 bbl per day fresh feed capacity using synthetic catalyst, calculations show that approximately 95,000 lb of 450 psi pressure 660 F temperature steam could be generated per hour from the sensible heat and the carbon-monoxide heat of combustion on this unit. This is an appreciable volume of steam for a high circulation of catalyst and this discussion will be confined to the possible installation of a CO boiler on a heat-balance-type unit. The use of a heat-balance-type fluid unit versus the nonheat-balance-type unit is determined primarily on the basis of unit flexibility. In the heat-balance-type unit the heat liberated from the burning of the coke on the catalyst is used to preheat the incoming feed and supply all heat necessary for the cracking reaction. This calls for a high circulation of catalyst in order to heat the feed entering the reactor to cracking conditions. As the name implies, no outside source of heat is required.

Assistant Technical Manager, The Pure Oil Company, Chicago, Ill. Mem. ASME.
to approximately 110,000 lb per hr, the auxiliary fuel accounting for 15,000 lb of the total production.

With fuel at 16 cents per million Btu a total volume of 110,000 lb of steam per hr would be obtained at a fuel cost of 3.6 cents per lb of steam or approximately 15 per cent of what the cost would be when generated on a conventional boiler. The large volume of steam generated from the carbon monoxide is considerably higher on this unit than is shown in the paper because of synthetic catalyst. The analysis of flue gas obtained from synthetic catalytic operation shows a lower carbon dioxide-carbon monoxide ratio or the CO content is higher and correspondingly the recoverable heat of combustion of CO is higher.

The choice between natural and synthetic catalytic is generally governed by the desired product distribution from each unit.

As mentioned, in some of our units the installation of a waste-heat generator to utilize only the sensible heat of the flue gas from 1050 down to 600 °F has been used. With this installation approximately 25,000 lb of steam per hr could be generated on a 20,000-hp fluid unit. The necessity for this installation was immediately apparent in order to obtain the desired steam temperature. This installation is considerably less expensive than the boiler described in the paper. However, the main disadvantage to this type of installation is that when the fluid unit is taken off line, steam generation ceases; the CO boiler, on the other hand, can be operated at rated capacity as an entirely separate unit with the use of auxiliary fuel. This means that the CO boiler has a continuity of steam generation independent of the fluid unit operation.

From an economical basis the installation of a CO boiler has very good pay-off and the decision as to whether to install this type of boiler depends entirely on whether the steam is required over existing boiler capacity. If the steam condition is such that an additional boiler is required then it appears desirable to install a CO boiler. This statement is made on the basis that whereas a conventional boiler would cost in the neighborhood of $5 per lb installed, the CO boiler will run approximately $8 per lb of installed capacity. It is true that the additional $3 cost per lb has a very rapid pay-off, but justification has to be made for the original $5 cost per pound. It can be seen, therefore, that with all the good features of the installation the final conclusion depends on the steam picture in a particular plant.

R. C. LAASSAAR. At Sun Oil Company, where we were among the first to utilize catalytic cracking, we have been cognizant of the waste of energy resulting, in the various catalytic-cracking processes, from the very substantial amount of carbon monoxide liberated by the combustion of coke on spent catalyst and from the sensible heat of the flue gas rejected to the air.

As a matter of fact, we have determined that the potential energy thus available, as of the beginning of 1954, from all catalytic-cracking plants, was of the order of 10,000,000 bbl of fuel oil per year. These figures were presented in a paper given at the 1954 mid-year meeting of the American Petroleum Institute.

We have approached the problem in two ways. In those units where it is desirable to produce only the amount of steam corresponding to the energy available in the flue gas, after thorough large-scale testing, we have used a new oxidation catalyst of the type developed originally to oxidize carbon monoxide and unburned hydrocarbons from lift trucks. We are presently erecting two new waste-heat boilers—one at our Toledo Refinery and one at our Marcus Hook Refinery, in connection with the construction of new catalytic-cracking units of the Houdriflow type. Flue gas will be passed through "Oxy-Cat" elements, arranged in a shallow stack at the bottom part of a boiler of more or less conventional design. Combustion of carbon monoxide will raise the temperature of the flue gas from 900 to approximately 1500 °F. The sensible heat, recovered in the boiler-economizer system, will result in the production of some 45,000 lb of superheated steam per hr. Conventional burners installed in the boiler provide the full start-up capacity.

The Babcock & Wilcox Company has designed and is erecting the boilers. The design of the flue-gas system, including the lower Oxy-Cat furnace, has been developed by the Oxy-Catalyst Manufacturing Company at Wayne, Pa., the Alcorn Combustion Company of Philadelphia, and Sun Oil Company.

In addition to the waste-heat-recovery units, we also will install a secondary waste-heat-recovery system operating on a small fraction of the flue gas which is kept under a pressure of 2 to 3 psi in order to supply the prime mover for pneumatic lifting of the catalyst. Again, a bed of Oxy-Cat elements will insure combustion of the carbon monoxide, liberating about 10,000,000 Btu per hr. The sensible heat, from 1500 to 1000 °F, will be recovered by a forced water-circulation continuous coil connected in parallel with the water-circulating system controlling the temperature of the catalyst in the regenerator according to conventional practice in units of the Houdriflow type.

The design of this latter unit has been developed by the Alcorn Combustion Company and Sun Oil Company and will use catalyst furnished by the Oxy-Catalyst Manufacturing Company.

In another development connected with our Toledo operations, we were faced with having to produce substantially more steam than the potential energy available from our existing catalytic-cracking unit. We arrived at the same conclusion as Sinclair, that, with little excess air, if enough outside air was supplied to the flue-gas steam to increase its temperature to the range of 1500 °F and the products of secondary combustion were mixed thoroughly with the incoming flue gas, then combustion of carbon monoxide would take place.

Since the steam requirements were substantially above this minimum point, we arrived at a design where the flue gas is introduced at a multiplicity of points at the bottom of the boiler and mixed with the products of additional fuel combustion in the firebox itself, rather than in a separate furnace.

This boiler was brought on stream in March, 1954, and has performed to our complete satisfaction. The total steam generation (450 psi, 560 °F total temperature) has been, as per design, 150,000 lb per hr, some 50,000 generated from the carbon monoxide and the sensible heat of the flue gas. The major part of this steam is expanded in a 3000-hp back-pressure turbine driving a centrifugal gas compressor associated with another process unit. Steam at 175 psi from the turbine is furnished to the refinery system, where it is used for the various requirements of the oil-refining processes. We have shut down the old low-pressure boilers which formerly were used to supply steam to our 175-psi system. When the catalytic-cracking unit is shut down for cleaning, the boiler can be fired at a total output of 225,000 lb of steam per hr, providing easily the starting-up requirements of the cat cracker in both low-pressure and high-pressure steam. The operation of the CO boiler has thus served the dual purpose of utilizing substantial amounts of waste heat, as well as making available high-pressure steam for a back-pressure turbine which has inherently the highest thermal efficiency attainable.

The design of the CO boiler was developed by The Babcock & Wilcox Company and Sun Oil Company, the former company having built and erected the boiler proper.

The authors are to be congratulated for their very valuable paper.

It is gratifying that, through independent thinking, we solved the problem of waste-heat recovery by different methods, arriving at the same final result.
The development of temperature control in the fluid-bed catalytic cracker at Houston by direct cooling coils is a real contribution to the art of catalytic cracking.

E. H. MANNY. Sinclair Refining Company's policy of maximum fuel economy has paid off once again with a calculated fuel savings of approximately $800,000 in the first year of operation of the CO boiler installation at its Houston Refinery. The success of this installation is a personal tribute to Mr. Campbell, who conceived the idea and spearheaded the project, and Mr. Pennels, who aided in bringing the project to completion. With the success of this unit, it is now definitely established by experience that recovery of both sensible heat and heat of combustibles from the CO gases from a fluid-catalytic unit is not only possible, but economically desirable.

The authors describe in considerable detail the background leading to the development of the CO boiler and the performance data obtained. A few comments will be made on the case of operation and some of the things anticipated in the design stages. On any new and untried application of this sort it can be expected that difficulties will arise when starting up and it is significant that the things we anticipated might be troublesome simply did not materialize. For instance, we thought it might be rather tricky to admit the CO gases to the boiler but actually it was a very simple operation.

It was anticipated that we might have trouble with ignition of the CO and flame stability but, thanks to the cyclonic action and turbulence of the gases in the furnace, excellent stability of combustion conditions was realized. Thermal stresses and erosion caused by the 1000 F CO gases were expected to be severe on the CO duct lining, and a costly application design was used. Actual results, however, showed that the lining held up much better than anticipated, although there can be considerable improvement in the design.

The most severe service probably occurs in the water seals when switching from by-pass to main-line operation or vice versa, requiring draining of one seal, filling the other, introducing hot gas over wet insulation, or quenching hot insulation. As was expected, this proved to be one of the greatest weaknesses, but the insulation stood up remarkably well, requiring only one large patch in the area near the outlet of the main-line seal. Improvement in insulation for this service is desirable.

In the design stages, erosion was considered a very definite possibility but did not prove out under actual conditions, as evidenced by the catalyst accumulation on the economizer tubes and some of the rearmost tubes in the boiler bank. Incidentally, because of the erosion possibility, it was originally considered that soot blowers might be unnecessary but actual results now prove otherwise. However, we feel that the catalyst adhering to the economizer tubes can be eliminated by raising the steam blowing pressure, although it might be necessary to revise blower spacing and increase their number.

The writer’s company now has in service, or on order, seven CO boilers; the Sinclair Boiler described in this paper, a sister boiler of about the same size and design at the Watson Refinery of Richfield Oil Corporation which has been in satisfactory service since June, 1954, a more conventional furnace design at Sun Oil Company’s Toledo Refinery in service since March, two oxy-catalyst-type recovery units presently in advanced erection stages, one at the Marcus Hook Refinery and the other at the Toledo Refinery of the Sun Oil Company, a new special design, circular, water-cooled CO boiler at Sinclair’s East Chicago Refinery in preliminary erection stages; and a similar but smaller circular boiler for Imperial Oil Company’s extension to the Halifax, Nova Scotia, Refinery.

Some time ago the company studied the potentiality of this new field of boiler application and concluded that the advantages were sufficient to warrant a boiler designed especially for this type service. Because design, fabrication, support, and insulation of the CO ducts is expensive and the ducts themselves require maintenance, our first objective was to eliminate as many of these ducts as possible. We were successful in doing this by combining the CO plenum chamber in a water-cooled “hustle” on the lower portion of the furnace formed by bending out every other tube and eliminating all but one CO duct connection from the main-line seal to the plenum chamber, thereby reducing greatly the number of expansion joints and purge air consumption. This same hustle also combines with it the wind box for the auxiliary burners, simplifying its construction.

The excellent combustion features obtained at Houston were maintained in the circular boiler, which we believe is essential in this type unit.

Also, since the entire furnace-wall enclosure is circular it possesses the inherent strength of a cylinder, eliminating the necessity of expensive buckstays and simplifying the casing design while, at the same time, improving the general appearance.

The authors are to be congratulated for their excellent presentation on this timely subject.

I. N. SCHARNBERG. The thermodynamics of oil refining is interesting in that they seem to resolve themselves into a series of anomalies. For instance, tremendous quantities of heat are required to raise the temperature and pressure of crude oil received to extremely high levels in order to separate, distill, crack, or reform into the various grades of gasolines, oils, greases, etc., required by the customer. It then seems necessary to expend additional heat energy to recoil these various products down to atmospheric temperatures, and pressures, in order to deliver to the customer. In like manner, more heat is utilized in the form of power, either steam or electrical, to transfer the crude oil into the stills, through the stills, recycle various stocks, and, finally, transfer the various resulting products to storage tanks and ultimately to ships, tank cars, or trucks, or all three. More power is required to pump the great quantities of cooling water and cooling air required. Additional heat energy is needed in the form of steam for decreasing vapor tension of boiling oil, reheating various components for close quality control, for stripping, for fuel atomization, for fire quenching, and ultimately for “steaming out” for safety, vessels ready for inspection and cleaning. The source of all of this heat energy required is the percentage of the original barrel of crude that is used for fuel. This runs as high as 10 per cent in some of the older refineries.

The reduction of this fuel requirement is the realm of the refinery combustion engineer. Equipped with a knowledge of thermodynamics equal to or exceeding that of the process designer he must further be an expert in physics, chemistry, mechanics, combustion, heat transfer, design, water treating, power generation and usage, operation, human understanding of both labor and management, economics, finance, and finally salesmanship, to accomplish reduction in the fuel consumed in a refinery.

Such engineers have cleverly used heat exchangers, condensers, air coolers or heaters, waste products such as sludges, cokes, tars, pitches, sour gases, waste-heat boilers, radiant-cracking still furnaces, back-pressure turbines where heat balance permitted, and other ingenious applications of their particular science. It is believed that a certain fixed-bed type of catalytic-cracking unit so
popular during World War II would not have been economically feasible except for the application of the gas turbine to this unit’s cycle of operation converting the large amount of heat liberated in revivifying the catalyst to supply the enormous power requirements.

This paper describes another forward step in attaining maximum fuel economy. The adaptation of a practically standard boiler equipped with a special pressurized primary refractory furnace carefully designed to handle the great quantities of low Btu gas is carefully and skillfully laid out. Its adaptation to the fluid catalytic-cracking unit should and did give the expected results in recovering both the sensible heat and the heat of combustion of the carbon monoxide contained in the regenerator flue gas. The result (including the superheater) of more than enough steam production to drive all pumps and blowers at a primary fuel cost of about 1/4 of that required to make that same amount of steam in a regular boiler is very impressive and gives alert management another means of reducing operating costs with incrementally small investment increase for CO ducts, seal tanks, and primary refractory furnace.

Engineers are usually very cautious in working out a new idea and those men have followed that pattern in the installation of unnecessary automatic control equipment for primary furnace temperature. It is now easy to see that with a unit like a fluid catalytic-cracking unit, manual operation would be all that was required. Doubtless this decision had as much discussion as that which resulted in the installation of retractable soot blowers. Results doubtless would have been quite different had soot blowers been omitted.

It seems to the writer that the decision to make only saturated steam from this boiler was a wise one, particularly since wide variations in volume of gas when burning all fuel oil or gas and when burning maximum CO through a simple superheater would result in wide variation in exit steam temperatures. He, therefore, regards the installation of the respray steam superheater in the regenerator fluidized bed as an excellent additional tool for operator control of regenerator-bed temperature. The idea of using forced-circulation water and a boiler for this control is not new and most problems have been found and conquered. However, the use of a superheater for this total control is, we believe, completely new and a seemingly logical step. The superheater coils are simple in construction, the use of Croloj’5 seems to have been successful, the use of automatic controls and desuperheating stations appears well thought out and with known standard control equipment should offer no problem.

We understand, however, that in their 1955 model now being installed at the East Chicago Refinery, Sinclair is installing a standard “attemperating” type of desuperheater directly in the CO boiler instead of the dual-purpose type in the fluidized bed as described in the paper. Will the authors explain why such change is being made?

B. E. Varon.7 The CO boiler now in operation at the Watson, Calif., Refinery of the Richfield Oil Corporation is essentially the same model as the Sinclair, Houston, boiler. Richfield decided to invest in this radically new type of heat-recovery equipment long before the Sinclair project was completed, as a part of its new $40,000,000 refinery-expansion program.

Several changes were made to suit the Richfield design before the unit went into construction. In addition to the nine tangential carbon-monoxide and nine refinery gas burners in the lower furnace, there were six combination B&W gas and oil burners in the upper conventional boiler. The combination of the two furnaces was designed to supply the total output of 340,000 lb per hr of 700-psi steam at 750 F, exclusive of any regenerator flue gas from the 63,000 bbl per day fluid catalytic-cracking unit.

The boiler also was equipped with a two-pass pendant-type superheater with an interbank attemperator. In addition, a Buel electrostatic precipitator was installed after the economizer to maintain the amount of catalyst dust to the atmosphere, within Los Angeles County limitations. This is 40 lb per hr maximum, regardless of the size of the unit. To date, the precipitator has been meeting these requirements satisfactorily, and is operating at 55,000 volts, and handling up to 420,000 cfm of 550 F flue gas from the boiler.

At present, the boiler is operating at a pressure of 15 in. of water in the lower refractory furnace which is averaging between 1650 and 1800 F. With the fluid cracker operating at full rate, the boiler has produced 370,000 lb per hr with only the lower furnace in operation. As in the Houston boiler, it has been unnecessary to use automatic combustion control because of the small variation in the amount and temperature of the regenerator flue gas. The Diamond IK retractable soot blowers have successfully kept the boiler and economizer clean. We have not seen any build-up of catalyst as yet in the boiler, economizer, or precipitator.

Exclusive of any sensible heat, the Richfield CO boiler has been saving 147,000,000 Btu per hr from the burning of the carbon monoxide, which would have been wasted, in a conventional type of unfired waste-heat boiler. The savings in fuel consumption from the combustion of the carbon monoxide alone, amounts to a total of $1,000 per day, at 28 cents per million Btu. In addition, the elimination of large amounts of carbon monoxide, and lesser amounts of other combustible contaminants, has enhanced the value of the boiler from an air-pollution viewpoint.

Richfield considers the CO boiler as a successful operating unit which has had the approval of civic officials and The Air Pollution Control of Los Angeles County.

AUTHORS’ CLOSURE

 Regardless of the economics of the CO boiler of any design it is a tool to reduce air pollution. The CO boiler renders harmless the poisonous CO gases and completely burns any hydrocarbons or unburned gas that may be contained in the CO-bearing gases. It appears that the oil industry has an obligation to the public to provide cleaner air and the installation of CO boilers to fluid catalytic-cracking units is a method to do so.

In reply to Mr. Scharnbarg’s question as to the reason for installing a superheater and attemperator on Sinclair’s East Chicago, Indiana, CO boiler, it can be stated that the East Chicago, Indiana, unit was equipped with regenerator catalyst coolers when the unit was built and additional catalyst cooling was not required. To provide steam superheat for process turbines a superheater was therefore necessary. To control steam temperature a mud-drum attemperator was installed. A steam superheater and spray-type attemperator was installed on the Richfield CO boiler because the Richfield fluid catalytic-cracking unit was of the heat-balance type.

In regard to Mr. Lassiat’s comments it appears to the author that a supplementary direct-fired CO boiler is preferable to a Oxy-Catalyst CO boiler to avoid the replacement and maintenance of the Oxy-Catalyst. The author experimented with an Oxy-Catalyst pilot unit and found that the catalyst from a fluid unit fouled up the Oxy-Catalyst and ignition was unreliable. With cleaner CO-bearing gases the Oxy-Catalyst should work satisfactorily.

In reply to Mr. D. S. Frank’s comments regarding economics, it is understood that with low-priced fuel it would not be economical to install a CO boiler where added steaming capacity is

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1 Richfield Oil Corporation, Wilmington, Calif.
not required but the obligation to provide cleaner air remains unsolved.

In conclusion, it is gratifying to observe that the Sinclair CO boiler is an acceptable tool for oil refineries equipped with fluid catalytic-cracking units to use where added steaming capacity is required or where it becomes mandatory to provide a cleaner atmosphere. The CO boiler may also be a useful tool for fluid coking units to conserve heat and clean up the atmosphere.