Conservation in Industry

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A little more than a year and a half ago, the Office of Emergency Preparedness undertook a staff study on *The Potential for Energy Conservation*. At the outset of this effort, the then somewhat novel idea was advanced that one might conserve fuels simply by using them more efficiently. One of the staff members working on the study asked knowledgeable persons in industry about that possibility, and was told that at the prevailing price of fuel, industry made the most efficient use of fuel possible. The implication was that economic justification had been considered in the various trade-offs that can be made to reduce fuel consumption, and further improvements in equipment to gain fuel efficiency would not have been justified.

However, a small group of industrial spokesmen began to tell quite a different story. For example, Dow Chemical began to publicize its internal energy management programs, which had resulted in steadily decreasing fuel consumption per unit of production for several years—years in which fuel prices had been declining relative to other prices. The measures applied to gain this improved efficiency of fuel use were economically justifiable, according to Dow.

Other spokesmen from industry, including representatives of Du Pont, Union Carbide, Thermo Electron, Surface Combustion, Bloom Engineering, Consolidated Natural Gas, and the American Gas Association, to mention only a few, told the same story: that there was significant latitude to improve the efficiency of fuel use in industry through measures that were economically justifiable at prevailing fuel prices.

On the basis of this preliminary information and some further staff study, the final report issued by the OEP included the possibility that, in some instances, industry might conserve fuels through more efficient use.

The potential for conservation of fuel through effective utilization began to attract the attention of numerous investigators, some of whom followed further the line of investigation of the OEP study. In conference after conference, university researchers, industrial engineers, business executives, and government scientists adduced evidence that it would be possible to save fuel and to save money too, in many industrial operations.

Today, in rereading the OEP report and the proceedings of the conferences that followed it, one can detect that the possible existence of economically justifiable measures to reduce industrial fuel requirements was given rather circumspect treatment. In fact, some of those who wrote and spoke on this subject confessed to a feeling of puzzlement. Their evidence indicated that many economically attractive measures to reduce industrial fuel consumption had been available, but had not been applied. This did not conform with the teachings of classical economics, that corporations would necessarily use all such measures to reduce their costs of operation.

As more evidence was brought out, those investigating fuel utilization in industry began to suspect that procedures of economic justification used in industry—particularly in small businesses and light industry—might depart significantly from the classical economic procedure advocated in textbooks and management schools, and upon which the economic justification of many fuel saving measures was based. In addition, investigators began to wonder whether there were factors in addition to technical feasibility or straightforward economic justification, which might exert an overriding influence on industrial decisions to adopt —or not to adopt—fuel saving equipment. Influences including those of political and institutional character may require examination if one is to explain why seemingly economically attractive fuel saving measures were not adopted in the past. It may, in fact, be necessary to find an explanation in order to plan for fuel conservation efforts in the future. If the influence of fuel price alone was not sufficient in the past to promote optimally efficient use of fuels, one may reasonably question the theory that the influence of higher fuel price will be sufficient to promote fuel efficiency to newly optimized levels. This will be considered further, below.

Present Measures

Nearly every newspaper, magazine, and professional journal one picks up today has an article on energy, and many of these articles concern improved fuel utilization in industry. For example, the 24 February *New York Times* carried an article by Gene Smith summarizing fuel conservation efforts by American Telephone & Telegraph, Litton Industries, TRW, Upjohn, Pfizer, General Electric, and other large corporations. An article in the *Wall Street Journal* on 11 March by Urban Lehner also dealt with efforts to improve efficiency of fuel utilization in such large corporations as Westinghouse, Dow, Du Pont, Greyhound, and RCA. The examples cited in these and other recent articles involved tuning up plant equipment, diligent management practices in plant operation, careful use of lighting and air conditioning, and other similar measures to eliminate outright waste of energy. The measures were said not to interfere with production, not to reduce worker safety or performance, and not to entail unjustifiable cost; in fact, in many instances, the fuel conservation measures were said to be accompanied by significant cost savings.

The quantity of fuel saved through the measures cited in current reports is impressive, especially in view of the simplicity of the measures themselves. For example, after requiring a daily report of the energy used by each department in its plants one corporation found that its energy consumption declined by 15 percent. Simple, straightforward steps such as adjusting combustion equipment and controlling plant ventilation have yielded fuel savings of 10 percent or more in many industrial plants. It appears that those who earlier expressed their belief that

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substantial quantities of fuel might be conserved through more effective use of energy in industrial processes have been sustained.

However, the present concern with fuel efficiency in industry follows a wave of unprecedented oil price increases and comes in a time when oil and natural gas may be temporarily unavailable to industry at any price. Thus, it can be argued that what one is seeing in present industrial fuel conservation efforts is simply a readjustment to increase the efficiency of fuel utilization to a new and higher level which is justified at new and higher fuel prices. That is, today's fuel conservation efforts merely illustrate the power of fuel price to promote efficient utilization.

But the measures being applied in the industrial fuel conservation efforts today could just as well have been applied in the past, to save both fuel and overall costs of operation. For example, in one large manufacturing plant in the southeastern United States, the first major step in an overall fuel conservation program was to replace several hundred broken windows through which heated or refrigerated air had been leaking for years. An executive from this plant stated that at the outset of his firm's conservation program no one knew just how many broken windows there were. In a small plant located in northeast New England, a major fuel saving was attained through careful loading dock operations. The plant ships large goods, and to load cargo the trucks had to be pulled into the plant building. It was common practice to park trucks in the doorway to the plant, which, of course, required that the large loading door remain open. During the period of several hours required to load the truck, the heated air from the plant was allowed to escape freely to the outside. The correction of the major heat leak from this small plant cost nearly nothing, but saved significant quantities of fuel.

Many of the industrial fuel saving measures reported in the press (and cited above) fall in the category of housekeeping, and as such can be adopted at little or no cost. These actions do save appreciable amounts of fuel and thus offer examples of economically attractive—but previously unapplied—measures for fuel savings in industry. However, the general tightening up of industrial maintenance, housekeeping, and energy management which has taken place recently—with highly salubrious effect—does not provide a measure of the full potential for the improvement of fuel utilization which might be gained through investment in improved equipment, and other capital projects. Nor does the history of housekeeping measures indicate the sort of influences which factors other than fuel price might exert on the decisions involving capital projects to improve fuel efficiency.

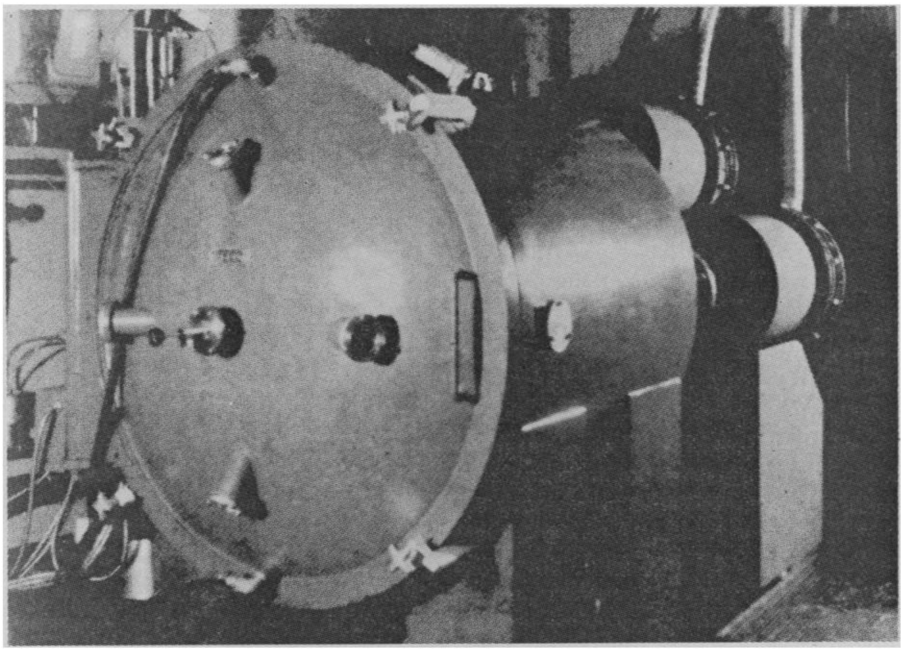

Fig. 1. A large heat-treating furnace, with the insulated water-cooled skid rails used to convey material through the furnace.

One of the first things industry might do to improve fuel efficiency would be to reexamine technical measures that have been available in the past. This is, in fact, taking place today, and at a vigorous pace. A few examples of some capital projects are offered here as an indication of the significance, range, and economic attractiveness of the fuel savings they offer.

Insulation of Heat-Treating Furnaces

Figure 1 shows a large heat-treating furnace used in the steel industry. Steel slabs are conveyed through the furnace on skid rails. These rails must be water-cooled so that they will not soften and collapse. The water-cooled skid rail system is an excellent way to remove heat from the inside of the furnace. Insulation can be applied to these rails to reduce heat losses, as the rails shown in Fig. 1 demonstrate. The insulation wears out as the furnace is used: One type of insulation currently marketed will last about 4 months with normal use, while a newer form of insulation is expected to give a year of service. Industrial experts estimate that approximately 50 percent of the water-cooled skid rails in heat-treating furnaces in the United States are fully insulated, while approximately 90 percent of those used in the major steel producing countries abroad are fully insulated. Further, industrial studies of the use of such insulation indicate that if insulation were applied to the presently uninsulated skid rail systems in the United States, the total saving of fuel would be equivalent to approximately 30,000 barrels of oil per day (1 barrel = 0.16 m^3) (*1*).

Now, the essential question about such a measure is, does it pay? Powell (*2*) has considered this question, and his data (Table 1) show that the expenditure of approximately \$100,000 on insulation can save approximately \$234,000 worth of natural gas per year. Whether one wishes to use the same tax or interest rates as Powell, the economic justification of furnace rail insulation is clear.

Many similar studies of furnace insulation, combustion control, burner positioning, and similar capital improvements in heat-treating furnaces have been carried out. Some of the more notable studies have been conducted by J. D. Nesbitt of the Institute of Gas Technology (*3*). Nearly all the studies available reach the same conclusions. Small additional investments in furnace insulation and similar capital projects yield significant savings of fuel and are very attractive economically.

The price of natural gas used in the studies cited here, $0.72 per thousand cubic feet (1 cubic foot = 0.028 m^3), is not exceptionally high. Some plants were paying this for firm gas contracts well before the present fuel crisis. The economic justification of the measures considered here was established well before the present trend of rapidly increasing fuel prices set in.

Industrial Furnace Efficiency and Heat Recuperation

A large part of the heat of combustion of the fuel used in high temperature industrial furnaces is lost in the exhaust. Table 2 gives data assembled by Hemsath (4), showing the efficiency of various types of industrial furnaces. Note that in many furnaces 50 percent or more of the energy used goes up the chimney.

There are no data in Table 2 for one important industrial furnace—the glass melting furnace. As a rule, these are large installations and involve regenerative heat recovery stages which are several times larger than the melting chamber (tank) of the furnace itself. These furnaces are generally designed to have extremely long lives, as industrial equipment goes, and careful economic justification is applied to their construction. The result is that large glass melting furnaces may be the most efficient of large high temperature in-

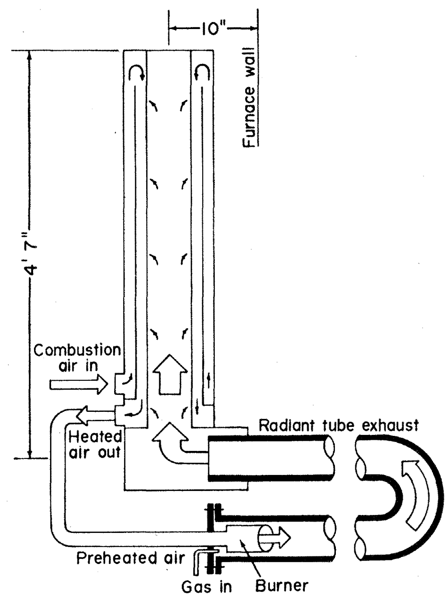

Fig. 2. A heat recuperator suitable for recapturing stack gas heat from a radiant fired tube and using it to preheat combustion air.

dustrial furnaces—the only possible rival being some steel furnaces.

For the rest of the furnaces listed in Table 2, it would be possible to use heat recovery equipment, such as heat recuperators, to recapture some of the heat normally lost in stack gases. One type of heat recuperator is illustrated in Fig. 2. This is designed for use with a radiant tube furnace, in which combustion is used to heat a tube through which the combustion products flow from the burner tip to the exhaust stack. The hot tube then radiates heat to the charge in the furnace. The recuperator in Fig. 2 draws fresh combustion air down over the outside of the exhaust stack, and thus uses part of the heat normally lost in the exhaust to preheat the combustion charge.

The effectiveness of using heat recuperation for such purposes is indicated by the data of Fig. 3, which were assembled by Kemsath. The data may be interpreted as follows. The process being executed in the furnace sets the flue gas exit temperature. Thus, for a process at, say 2500°F, the fuel to be saved by preheating combustion air to various temperatures can be determined directly from Fig. 3. For example, preheating the combustion air to 1000°F reduces the total fuel consumption in the furnace by more than 30 percent (5).

Direct heating operations in industry, such as heat treating, smelting, and glass melting, account for approximately 11 percent of the total fuel consumption in the United States (6). It appears possible that as much as 30 percent of the fuel in certain direct heating operations can be saved through the use of devices similar to the one in Fig. 2.

As for the use of such devices on radiant tubes alone, there are approximately 900,000 radiant tubes in heat-treating furnaces in U.S. plants, and very few of them are equipped with heat recuperators. Heat recuperators are being introduced to the market now for this purpose. Industrial estimates indicate that each recuperator can save fuel equivalent to ½ barrel of oil per day. Recuperators cost $1000 to $1500 per unit. The total potential (equivalent) fuel saving for all the radiant tubes in operation today is of the order of 450,000 barrels of oil per day. Furthermore, a device costing $1000 to $1500, which will eliminate the need for ½ barrel of oil per day (equivalent) is economically rather attractive now (7).

Table 1. Costs and benefits of insulating water-cooled skids in a reheat furnace. The furnace capacity is 160 tons per day; insulation reduces heat input by 40.3 million Btu per hour. Fuel, at $0.72 per thousand cubic feet, is reduced by 40.3 thousand cubic feet per hour. Data are from Powell (2).

Item	Annual amount (dollars)
Capital cost	100,000
Operating cost analysis	
Maintenance, 5 percent of capital cost	5,000
Taxes and insurance, 2 percent of capital cost	2,000
Interest, 4.5 percent of capital cost	4,500
Depreciation in 1 year	100,000
Total annual operating cost	111,500
Economic benefit of fuel use reduction	
Annual fuel cost reduction*	243,734
Annual cost	111,500
Annual benefit	132,234

* Calculated on the basis of 40.3 thousand cubic feet per hour, at $0.72 per thousand cubic feet, for 8400 hours per year.

On-Line Computer Controls

The use of computer controls in the operation of large thermal processing plants is a most attractive way to save fuel and reduce costs. In one European steel plant, the use of on-line computer controls to execute a carefully devised program of operation for steel reheating resulted in a 25 percent reduction in fuel consumption per ton of production, and was accompanied by a 12 percent increase in the plant's rate of production (8). The functions monitored by the computer included the furnace idling temperatures, the temperature of the charge in the furnace and in passage from furnace to furnace, and the speed of passage of the charge. One of the virtues of using the computer control system was that once a planned schedule of operation was programmed it could be met. This was a key element in increasing the productivity of the plant. The investment in the computer control system was clearly justifiable for the steel company.

On-line computer controls are also very useful for combustion equipment. Regulation of combustion air is most important for the efficient operation of high temperature industrial furnaces; excess air quenches the flame temperature and reduces the efficiency of heat transfer to the furnace. Combustion equipment, particularly oil-fired equipment, can be thrown out of adjustment by rapid changes in atmospheric conditions, and by other phenomena, such as progressive fouling, which might be thought to be of minor importance by anyone except a combustion expert. Industrial experts have studied the significance of proper burner adjustment and maintenance (*9*), and many have concluded that, in the case of burner units which are not equipped with on-line continuous stack gas analysis and feedback control, diligent application of exacting adjustment procedures could save 5 to 10 percent of the fuel consumed. Some field measurements have shown fuel savings of as much as 30 percent. The wider application of combustion control systems would appear to be an economically attractive avenue to promote industrial fuel efficiency (*10*).

Accelerated Adoption of Improved Equipment

The examples discussed above involve capital improvements of existing plants or new plants of conventional design. It is also possible to adopt new plant design to improve industrial fuel efficiency.

One often hears speculations that it might take 15 years or more to effect substantial changes in large industrial plant equipment. But it would be a mistake to underestimate just how rapidly industry can change, when the incentives involved are sufficiently strong. For example, the Pilkington float glass process for producing flat glass received its large international

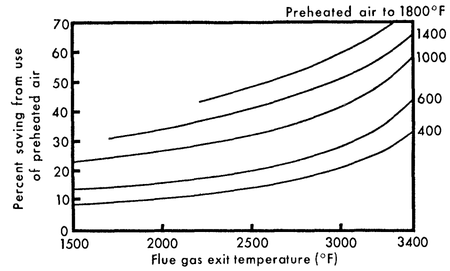

Fig. 3. Effectiveness of combustion air preheating as a measure for saving fuel. The data are from K. Hemsath.

marketing push in the middle and late 1960's. In the early and middle 1960's most flat glass produced in the United States was made in plate glass plants. The Pilkington process, although significantly more costly to set up as a rule, is much more efficient in its use of all factors of production, including fuel. The result of the introduction of the float glass process has been that, in somewhat less than 10 years, flat glass production in the United States has been converted from plate glass production to a state in which only one plate glass plant remains in operation, and the remainder of the country's flat glass is made as float glass. In one major flat glass plant, a new plate glass furnace costing somewhat more than $15 million was operated only 1 year, and was then shut down because it could not compete with the float glass equipment installed next to it. Industry can indeed move very rapidly when the incentives are attractive. Far from requiring 15 years or more for significant changes to be brought about, industrial production can be revolutionized in less than a decade if the incentives are sufficiently strong.

Cement making is an industry in which one might see rapid changes in plant equipment. The average fuel consumption in U.S. cement kilns today is 1.2 million Btu per barrel of cement (*11*). The most efficient U.S. cement kilns, operating on a dry process, use approximately 750,000 Btu per barrel.

In European cement making, advances in heat transfer technology have been applied to reduce fuel consumption to significantly lower levels. The use of heat recuperation is the principal measure by which higher efficiency of fuel use in cement calcination has been achieved. Reject heat from a kiln is

Table 2. Efficiences of various types of industrial furnaces; D, directly fired; ID, indirectly fired. Data are from Hemsath (*4*).

Industry and process	Operating temperature (°F)	Type of heating	Heat distribution (%)	
			Process	Exhaust
Steel and alloys				
Annealing	1450–1650	ID	35	56
Normalizing	1575–1700	D	43	46
Hardening	1400–1600	ID	36	38
Tempering	400–1200	D	54	32
Gas carburizing	1650–1700	ID	34	58
Carbonitriding	1300–1650	ID	35	57
Gas nitriding	950–1050	ID	45	40
Reheating	2200–2300	D	30	65
Sintering	2000	D	38	53
Brazing	2000	D	38	53
Aluminum				
Ingot heating	1100	ID	44	41
Coil annealing	800	ID	47	36
Solution heat treating	900–1025	ID	45	38
Strip heating	1000	ID	45	38
Copper and brass				
Ingot (coke) heating	1700	D	43	46
Annealing	600–1200	ID	44	41
Billet heating	1700–1800	ID	32	61
Solution heat treat	1700	ID	35	58
Strip heating	1300	D	51	36
Glass				
Annealing	100–1050	D, ID	45	38
Tempering	1250	D	53	34
Decorating	1200	D, ID	43	43
Bending	1250	D	54	32
Fabrication	1000–1400	D	47	41
Carbon				
Carbon baking	1600–1800	D	42	48
Rebaking	1600–1800	D	42	48

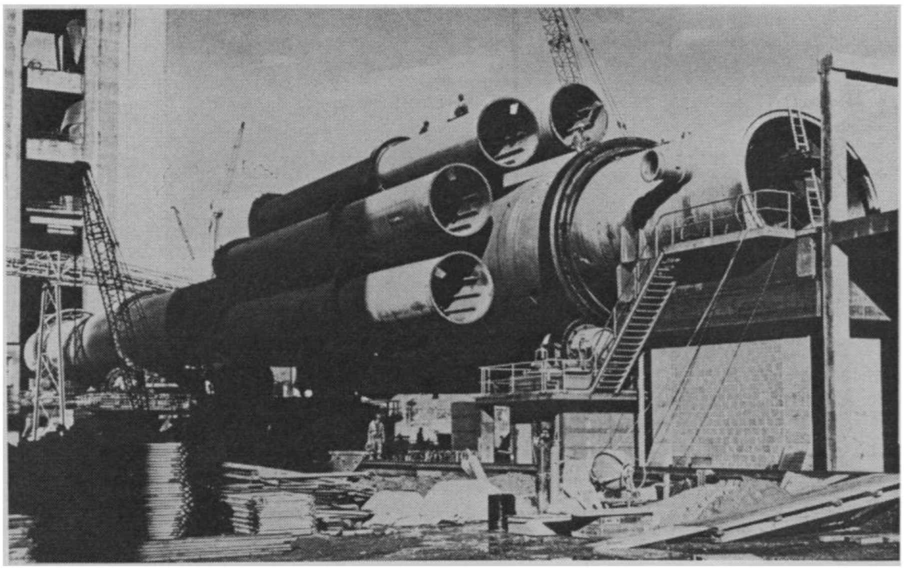

Fig. 4. A modern European cement kiln with multiple preheaters.

used to preheat the limestone charge before it is introduced into the kiln. A large, modern European cement kiln, equipped with several preheating units, is shown in Fig. 4. This type of kiln, which is being installed in Europe today, uses only 550,000 Btu per barrel of cement. This represents an efficiency of somewhat more than 55 percent.

There are further advances which can be introduced to cement kiln operations. Fluidized bed processing, for example, offers not only some further gains in fuel efficiency but some additional gains in flexibility of operation and speed of processing.

With fuel prices climbing and with energy purchases representing as much as 20 percent of the total operating costs of some cement plants, one should not be surprised to see the rapid application of new and more efficient equipment in this field.

Longer-Range Possibilities

Having looked at improvement of existing plants and at plant equipment of superior efficiency that is now available, we turn to the possible future use of equipment still under development. An example of such equipment is the heat pipe vacuum furnace (*12*).

The conventional design of a vacuum furnace calls for energy to be supplied via electrical resistance radiators inside the furnace. This means that for every Btu of heat delivered to the charge in the furnace approximately 3 Btu of fuel must be consumed at the electrical power plant that energizes the furnace. The temperature required in the furnace is often less than the adiabatic temperature of combustion of the fuel used at the power plant. In a prototype model, a heat pipe has been used to supply energy to the interior of the vacuum furnace from a local combustion chamber. In addition, certain modifications of insulation were applied to the vacuum furnace, to take advantage of the fact that the heat transfer from the charge to the furnace wall takes place entirely by radiation. The combined effects of using specially designed antiradiative insulation and a local direct combustion–heat pipe system to supply energy to the furnace reduced the fuel requirements for operation of the furnace by 75 percent, as compared with a conventional electric vacuum furnace. The elimination of the electric power generation was responsible for most of this saving. The principle on which this step is based is the use of energy at the quality required by the process (direct heat) rather than energy of excess quality (electricity). Figure 5 shows the Shefsiek-Lazaridis prototype vacuum furnace (*12*); note the combustion chamber at the rear of the device.

Another method of improving industrial fuel efficiency in the future is to combine industrial production of process steam (which accounts for approximately 17 percent of the total fuel consumption in the United States) with electric power generation. Many steam raising operations such as paper pulping, paper drying, and vulcanizing require low-quality steam (*13*). If one were to use additional fuel, and raise the steam to somewhat higher quality, it would be possible to pass the steam through a power generation plant and produce electricity, and to use the steam rejected by the steam turbines to operate the process for which the steam was originally required. Electric power is thus generated by using only the extra fuel required to increase the quality of the steam above that needed for normal operations. In this manner, power can be generated with very high efficiencies: heat rates as low as 4500 Btu per kilowatt-hour can be obtained. This compares very favorably with the most optimistic expectations for advanced technologies of power generation, such as magnetohydrodynamics.

An average paper plant could produce three to four times as much electrical power as it could consume. Thus, thermal integration of paper plants (and other similar steam raising operations) with electrical power generation could provide highly efficient growth in electrical generating capacity.

Is it actually technically feasible or economically attractive to build thermally integrated steam raising power generation plants? This scheme is but a minor variation on the currently popular notion of waste heat utilization at power plants. Instead of building a power plant and trying to find some use for the waste heat, one builds a steam raising plant and tries to find a use for the surplus electrical power generated. In addition, the idea is neither new nor economically uncertain. In the 1920's and early 1930's, several major paper companies used exactly the idea considered here. It proved to be a very profitable way to generate electrical power—so much so that in the 1930's the Department of Justice took an interest in the matter. In a series of court suits the paper companies were required to decide whether they were in the paper business or the electric power business, and most opted for the paper business, leaving power generation behind.

The technical feasibility and economic attractiveness of thermally integrated steam raising and power generation has long been established. The fact that the measure saves fuel is well established. The essential problem in trying to adopt such a measure is to find a way to do so which does not abridge other requirements of society, such as preserving open competition in industry. Much the same can be said of integrating power generation with direct heat processes in industry, as well.

Corporate Policy

We have seen that there are technically effective and economically attractive measures for conserving fuel in industry. If the measures are both technically effective and economically justifiable, should there be anything left to consider? Should not the influence of increasing fuel price alone stimulate their adoption to the economically optimal level? As some of the above examples indicate, this did not happen in the past. There may be some important problems left to consider after one has resolved all those of a straightforward technical and economic nature.

In a recent meeting between business executives and government officials, called to discuss energy use in industry, it was suggested that if the technical and economic problems of industrial fuel conservation were not serious, and yet industrial adoption of fuel conservation measures had not been rapid, problems of an institutional or political nature might be of overriding importance. The reception of this idea was less than enthusiastic: Several executives expressed doubt that researchers outside industry understand the real world in which industry functions (*14*). But one senior executive of a corporation which has been a leader in fuel conservation efforts acknowledged the validity of the question.

His answer (to which I subscribe) was that the problem was one of awareness. Senior industrial management in the past had not been fully aware of the economic potential of industrial fuel conservation. The recent oil embargo served to get management's attention more effectively than either the past entreaties of inventors of fuel conservation measures or forecasts of future fuel price increases ever could have done. Having become aware, the executive contended, industry would move, and more rapidly. He concluded by saying that his corporation expected to make a lot of money out of energy conservation. He is probably right, and this may be the biggest boost conservation could have.

But the executive was indicating that a major obstacle to adoption of fuel conservation measures in the past had been the institutional and political aspects of corporate policy and management. No matter how comprehensive human intellect might be, only so many things can be taken into consideration at any one time. Business executives are continually faced with a broad spectrum of problems to resolve (labor, material supply marketing, sales, and so forth), and only a few resources apply to controlling them. Until something happens to persuade the executive that control of energy use (or any one of a number of other considerations) must be taken into account, it probably will not be. The problems of controlling the use of increasingly costly labor or of expanding plant capacity on increasingly costly money, or other problems which, if unattended, are certain to lead to crisis, are likely to occupy the executive's attention fully. This is particularly true of small business and light industry, where margins of error are small. This is the classical mechanism by which opportunities are missed—not because the things considered were not well considered, but because not enough things were considered. After the recent oil embargo and price increases, control of energy use will be taken into consideration in almost every business decision.

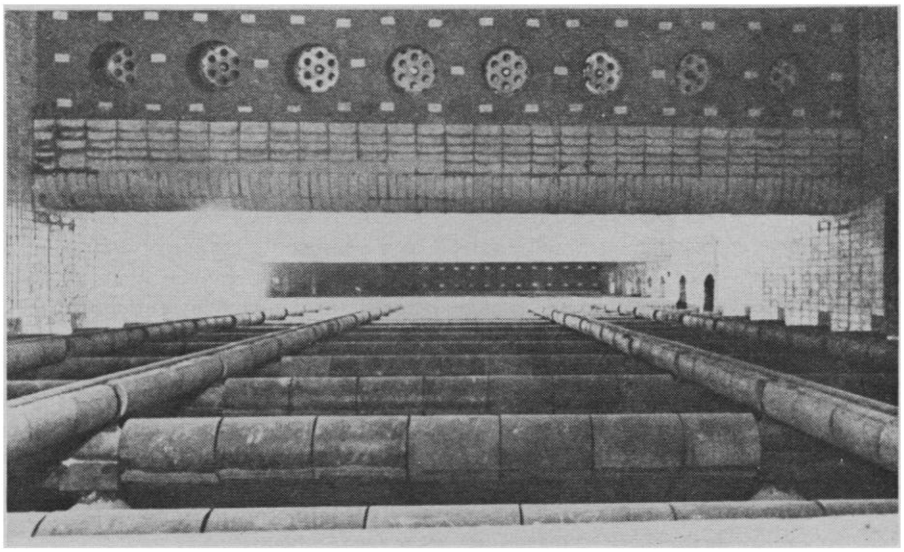

Fig. 5. The heat pipe vacuum furnace of Shefsiek and Lazaridis.

Some other factors affecting business decisions should also be taken into account. The economic justification of capital projects is considered in the process of budgeting. While the ideal model of budgeting would have one establish all projects in terms of a base budget, this rule is honored in the breach. It seems to be more common for yearly changes in the budget to be examined than the base budget itself. Thus, changes in the costs in various sectors of a production operation provide the signals by which the framework of budgeting actually is worked out in many corporations (and at many levels of government, too). An area in which costs are going up rapidly receives a great deal of attention; an area of declining costs may be viewed as a problem which is solving itself. This may help to explain why many measures for fuel conservation were not adopted in the past, because over the last decade or two energy prices have declined relative to other prices. If this view of budgeting, which has been expressed by numerous persons, is in any way correct, the fact that fuel prices are now rising may be an even more powerful stimulus to improving fuel efficiency than the present high level of fuel prices.

Lending policy also influences decisions, especially in small businesses. Most industrial fuel saving measures will require some capital projects, necessarily financed with borrowed money. With a very large part of the heat-treating equipment in the United States located in small corporations specializing in that field, the adoption of heat recuperators, furnace insulation, and other similar measures will require loans and will be influenced by policy governing loans. Businessmen and bankers who have discussed this subject seem to agree that loans for expanding plant capacity are usually given a higher priority than loans for improving existing plant performance. One consideration is that expansion of plant capacity promotes local employment. This has usually been given high priority in lending decisions, particularly in the recent past. Lending policies of this type may help to solve local unemployment, but loans to help improve fuel efficiency can have significant indirect effect on employment and can help control the consumption of natural resources in the process.

One should also consider the influence of technological risk—the risk that a new installation or new piece of equipment may not work as well as expected. This risk seems to loom largest in large-scale thermal processing equipment. In many instances, the laws of scaling used by engineers and scientists are simply not adequate to permit one to scale up a new type of cement kiln or a multifuel furnace from laboratory model to full production size, with sufficient accuracy to satisfy the economic constraints of the industry concerned. It is not a question of whether the scaled-up plant will work or not. But if the rate of production of some types of large thermal processing plants were to turn out to be several percent less than predicted, the owner of the installation might find himself in serious trouble. And, to repeat, the engineering scaling laws on which one must rely may not be sufficiently accurate, especially with regard to circumvention of instabilities. Anyone who has attempted to scale up a fluidized bed apparatus or a large ceramic structure will recognize the difficulty.

A basic problem here is that one is required to scale up the laboratory model to a full-scale facility. If one were able to experiment, modify, tune, and adjust one full-scale facility (say a large inclined fluidized cement processor or a large ceramic gas turbine) one could undoubtedly debug the full-size apparatus so that others could be reproduced from it and put into production without major difficulty. But few industries can justify putting up a large production facility on which experiments and debugging efforts are to be conducted.

The cement kiln of Fig. 4 runs well in Europe, but the limestone and aggregate used there differ from those found in the United States. Where dry process cement making is practicable in the United States such kilns could most probably be used, once some adjustments were made (*15*). But to say to a prospective owner of such a plant that it probably can be made to work here is to dampen his enthusiasm considerably.

In other countries, large-scale demonstration plants have been built to permit experimentation, tuning, and debugging of large-scale thermal processing equipment. Such demonstrations would be very helpful in U.S. efforts to resolve energy problems.

Finally, institutional, regulatory, and legal barriers can constrain the adoption of technology to improve fuel efficiency. The earlier example of integration of industrial steam raising and power generation illustrates this. Legal barriers have been erected for good reasons—they safeguard certain things which society deems essential. With fuel and other natural resources becoming progressively more precious to society, it may be necessary to reexamine some of the legal and institutional constraints established in the past. It may be possible to find ways to preserve competition, and other such valuable aspects of society, and to conserve fuels and other natural resources too.

Conclusion

There is a wide range of technical measures to improve the efficiency of fuel use in industry. The economic justification for adopting these measures can, as a rule, be readily established. If one can resolve the nontechnoeconomic constraints which affect the adoption of these measures, one can look forward to substantial reductions in the fuel required to operate many important industrial processes.

References and Notes

1. Most of these furnaces are fired by natural gas.
2. A. S. Powell, paper presented at the Cleveland State University Conference on Energy Utilization, Cleveland, Ohio, 24 October 1973.
3. J. D. Nesbitt, paper presented at the East Ohio Gas Company Seminar on Fuel Conservation in the Steel Industry, 20 April 1972.
4. K. H. Hemsath, paper presented at the American Flame Research Committee meeting at the Massachusetts Institute of Technology, Cambridge, 4 June 1973.
5. To convert temperatures to degrees Celsius, subtract 32 and divide the result by 1.8.
6. "Patterns of energy consumption in the United States," report to the President's Office of Science and Technology by Stanford Research Institute, January 1972.
7. Most radiant tubes are fired on natural gas, and most heat treating furnaces can be assumed to operate 8000 hours a year.
8. F. Hollander and R. L. Huisman, paper presented at the annual convention of the Association of Iron and Steel Engineers, Chicago, 1971.
9. H. C. Hottel and T. B. Howard, *New Energy Technology—Some Facts and Assessments* (MIT Press, Cambridge, 1971).
10. A number of large glass furnaces have been equipped with on-line computer control of combustion. Typically, these systems permit about 1 percent excess oxygen in the stack gases, which represents very efficient combustion conditions. However, some of the largest furnaces are not yet equipped, and manual adjustment procedures are used.
11. One British thermal unit (Btu) = 1.06×10^3 joules; 1 barrel of cement weighs 150 kilograms.
12. P. K. Shefsiek and L. J. Lazardidis, *Proceedings of the Second Natural Gas Research and Technology Conference* (Atlanta, Georgia, 5 to 7 June 1972).
13. The term quality is used here in the engineering sense: high-temperature dry steam is high quality.
14. It seems increasingly fashionable among public and private executives to describe one's own area of endeavor as the "real world."
15. Different aggregates react differently with cements having different processing histories. If dry processed cement is not properly controlled in the kiln, it can undergo deterioration in service through alkaline reactions with certain aggregates.