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Industrial Low Temperature Waste Heat Utilization

Mehmet Altin

INDUSTRIAL

LOW TEMPERATURE WASTE HEAT UTILIZATION

Mehmet Altin
Monsanto Company
St. Louis, Missouri

In this paper, some common and emerging techniques to better utilize energy in the chemical process industries are discussed. Temperature levels of waste heat available are pointed out. Emerging practices for further economical utilization of waste heat at the available temperatures or at higher temperatures are given with examples of some recent applications.

NOMENCLATURE

K Thousands, M Millions, Btu British Thermal Units

INTRODUCTION

According to the first law of thermodynamics all the energy that goes into a process has to come out eventually in some form. Except for products that require endothermmic reactions, most products have very little calorific value. That is, energy used in a process has to be rejected from the product or byproducts. Therefore, energy is not consumed, but it is utilized to accomplish a desired process. Since the energy into a process is the same as energy out of the process, what is it that accomplishes the desired process? It is the quality of energy that accomplishes something for us. The quality of heat energy that the chemical industry utilizes is related to the temperature at which it is transferred into the process. Since steam and process stream vapors transport most of the thermal energy, the saturation temperature of steam is a direct indication of the quality of the heat energy.

The higher the temperature of the energy, the easier it is to utilize it economically to produce more products. The energy that has high enough quality to be utilized economically is useful energy. The energy that has too little quality left to be utilized economically at any given time is rejected to ambient and therefore called waste energy.

When energy was very inexpensive compared to capital cost, the economically feasible thing to do may have been to save capital by simplifying the system by converting and utilizing energy at the required quality level for a single purpose only (see Figure 1). As the energy costs increase, it has become economical to utilize the same energy to accomplish more than one process, although this may require more capital for a more complicated system.

Two widely used applications of this concept are shaft power or electric power cogeneration and combining large numbers of processes so that some processes can use the so-called waste heat of some other processes. As shown in Figures 2 and 3, more products can be produced with lower energy when energy is utilized for multiple purposes and cogeneration, as opposed to single purpose utilization.

INDUSTRIAL WASTE HEAT

Although the chemical industry has used shaft power cogeneration and multiple purpose utilization of energy, especially with interchangers, it has been difficult to recover and utilize process byproduct energy under 300 °F. This is why most of the industrial waste heat is in the range of 300 °F to 130 °F. Waste heat under 130 °F is practically useless for industry because it is very close to ambient temperature and whatever difference there is, is used to reject it to ambient. It is estimated that over $2x10^{15}$

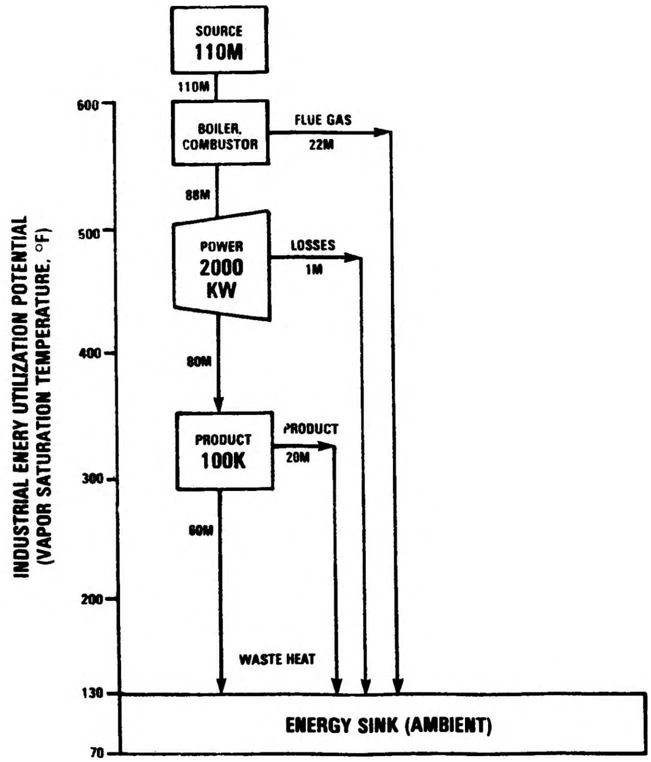

Figure 2. Cogeneration

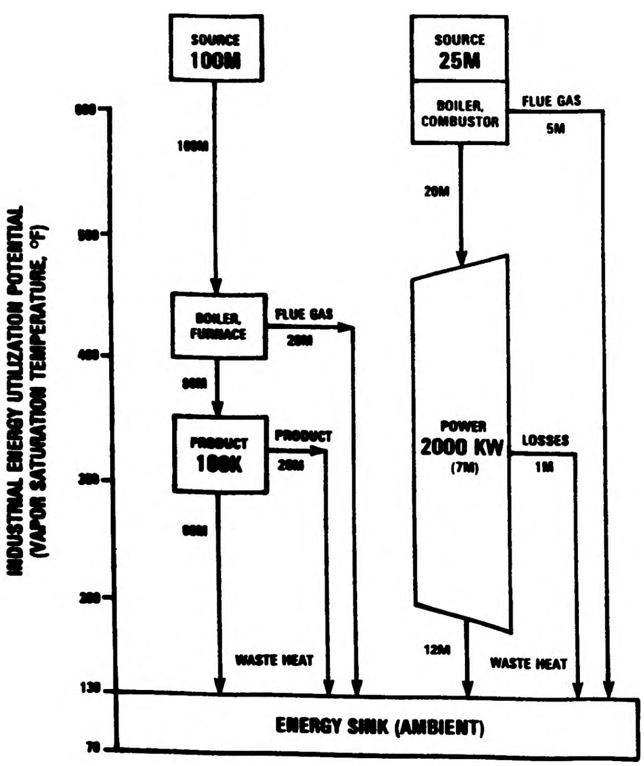

Figure 1. Single purpose energy utilization

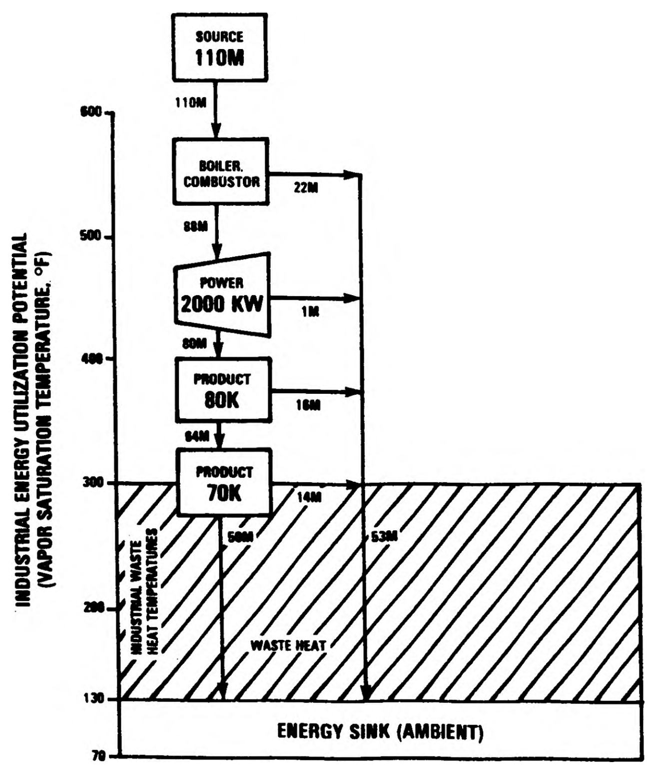

Figure 3. Cogeneration and multiple purpose energy utilization

Btu of industrial waste heat available in the streams shown in Table 1 is being wasted every year at 130 °F to 300 °F temperature.

Table 1
Available Industrial Waste Heat

Media	Temperature °F	%
Process Streams	300-130	65
Contaminated Condensate	200-130	5
Flue Gas	300-200	30

Increasing energy costs now give us economic incentives to recover and utilize some of this energy. For example, capital that can be justified to save one unit of energy has increased five fold since 1972 (see Fig. 4).

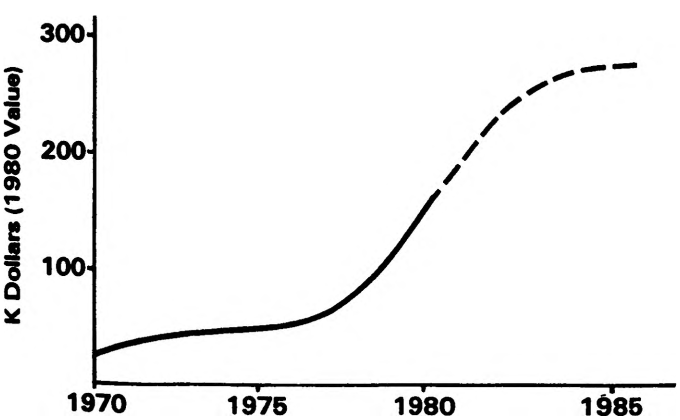

Figure 4. Justified Investment to Save 1 M BTU/Hr Heat at Boilers

It is expected that this trend will continue at least until 1985. With these new increasing incentives, we are now looking at techniques to recover and utilize the waste energy which were not economically feasible a few years ago.

These techniques can be classified into two groups (see Figure 5):

(1) Direct utilization of waste heat at available temperature.

(2) Utilization of waste heat by boosting its temperature.

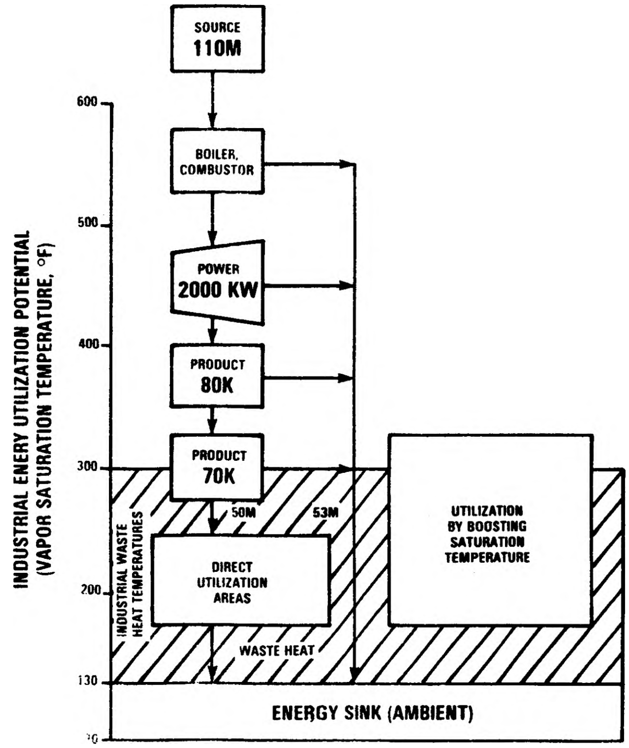

Figure 5. Areas where industrial waste heat could be further utilized as the rising costs of energy would justify

DIRECT UTILIZATION OF WASTE HEAT

In industry the most effective way to utilize waste heat is to utilize it to make more products which might have otherwise required a higher quality energy (see Figure 6A). This might require, however, that all or portions of the process be modified to be able to utilize lower temperature waste heat. Examples include decreasing process pressures or accomplishing process steps in more than one stage with some stages using waste heat and other stages using higher quality energy to complete the process. In one application, for example, double effect evaporation is used to increase production without increasing the higher quality energy use (see Figure 6B). In this application the latent heat of the vapors from the first evaporator is utilized at a second evaporator which is operated at a lower pressure.

If 220 °F waste heat were readily available, we could have operated both units at lower pressures thus eliminating new steam use completely.

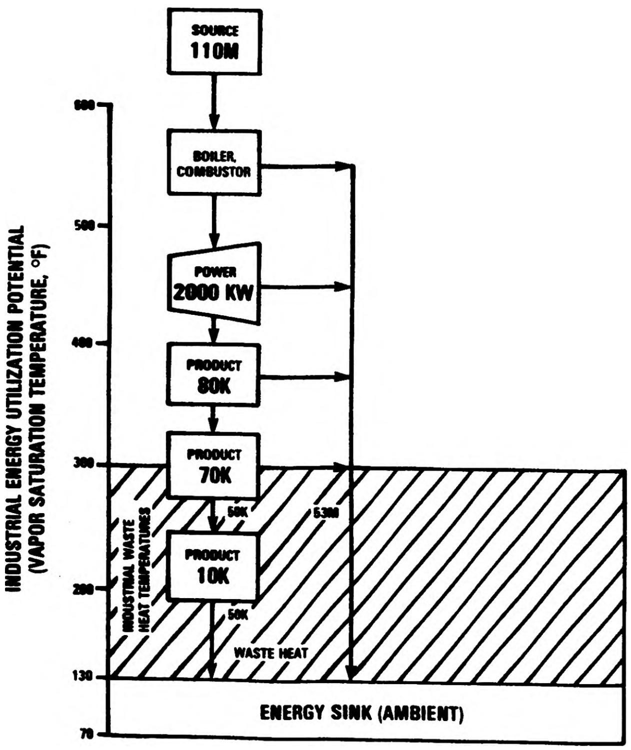

Figure 6A. Direct utilization of waste heat for increased production

As the energy costs keep increasing, the stages (effects) can be increased as much as technically and economically feasible. The same argument can also be applied to other processes such as distillation. For some particular applications, we have been able to justify triple effect evaporation and double effect distillation based on energy conservation or waste heat utilization.

If waste heat cannot be utilized to meet the process heating requirements, it could be utilized to save some power by using it in absorption refrigeration, provided theere is need for refrigeration (see Figure 7). However, it should be recognized that the power savings by this method are comparatively low. In order to be economical, the absorption chiller units will have to use only waste heat that cannot be utilized anywhere else. The presently available units also need 240 °F minimum temperature. There are some development programs which are trying to develop units that will be capable of using 140-200 °F waste heat, but commercialization is not expected soon.

It should be pointed out that even though there is a very large amount of energy in flue gases at fairly high temperatures (240-280 °F depending upon the sulfur concentration in the flue gas) this waste heat is virtually unre-

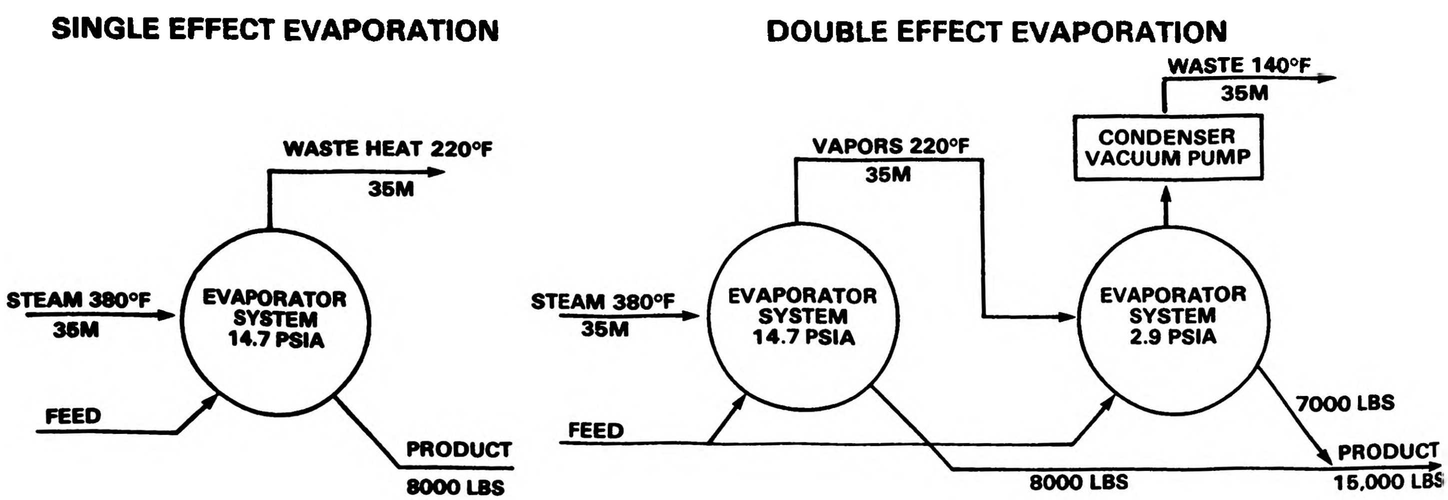

Figure 6B. Example 1. Direct utilization of industrial waste heat. Making more products of the same or different kinds.

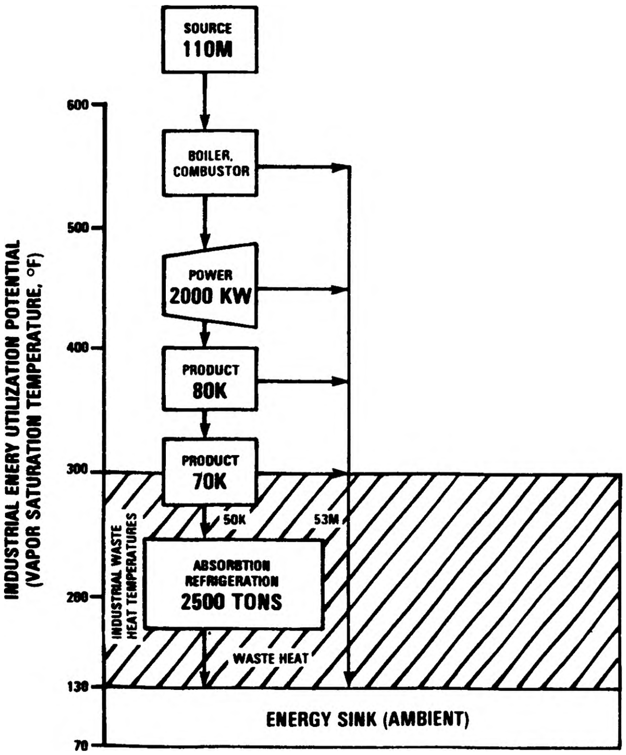

Figure 7. Direct utilization of waste heat for absorption refrigeration

coverable, because flue gas under these temperatures becomes very corrosive. Some companies are trying to develop corrosion resistant inexpensive materials and/or equipment for flue gas contacting surfaces.

WASTE HEAT TEMPERATURE BOOSTING

Direct utilization of waste heat as discussed above involves developing processes which are capable of utilizing energy at available temperatures. Another technique is to leave the processes as they are, but boost the temperature of the waste heat to required levels. In industry temperature boosting is normally accomplished by compressing waste heat laden vapors to a higher pressure thus increasing its saturation temperature. In some cases the process vapors are not suitable for this method. In those cases, waste heat is transferred to an intermediate medium such as one of the refrigerants and then this medium is compressed. Direct vapor compression is sometimes called "open cycle" heat pump. The cycle which has intermediate fluid is called "closed cycle heat pump".

Presently there are two methods that are being used in industry.

Thermal compression (thermocompressors, ejectors) - This method uses a higher pressure motive fluid in an ejector to compress the waste heat laden vapors (see Figure 8A). In order to be economical all of the motive steam should be utilized. Because of its simplicity and low cost, whenever the conditions are right this method provides attractive returns on investment. In one of our recent projects, for example, we have reduced steam use from 13 M Btu/hr 25 psig steam to 5 M Btu/hr 175 psig steam without reducing the production rate (see Figure 8B). In that project, part of the evaporated vapors were recompressed to supply heat requirements of the evaporator. In another project we are evaluating the feasibility of reducing steam use by 20 M Btu/hr by flashing a hot product to a lower pressure and recompressing the

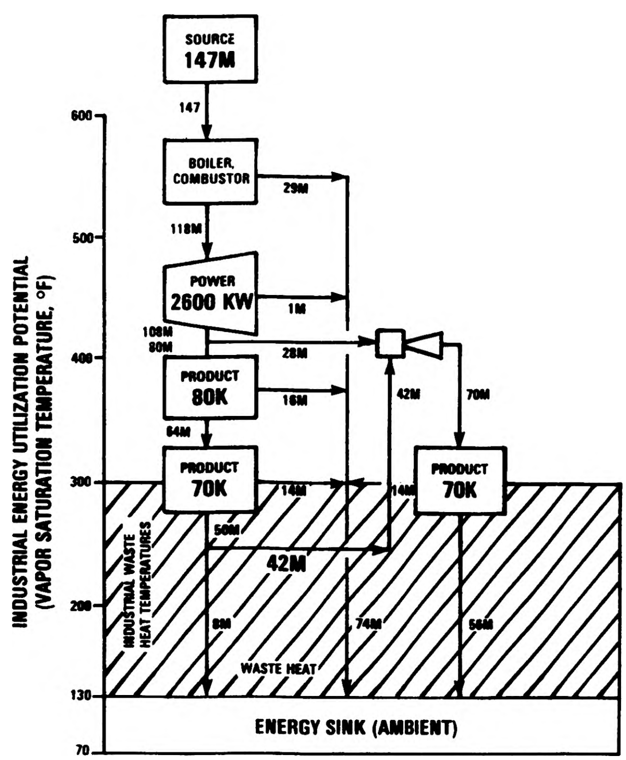

Figure 8A. Waste heat utilization by boosting saturation temperature with thermocompressors flashed vapors by thermocompressors to provide part of the heating requirements (see Figure 8C).

At this time, thermocompressors may be economically feasible for the following conditions:

(1) Waste heat available is 5 M Btu/hr or more.

(2) Compression ratios are less than 2 to 1.

(3) Differential temperature (boosting) is less than 50 °F.

For some applications it could be feasible outside the above conditions as well.

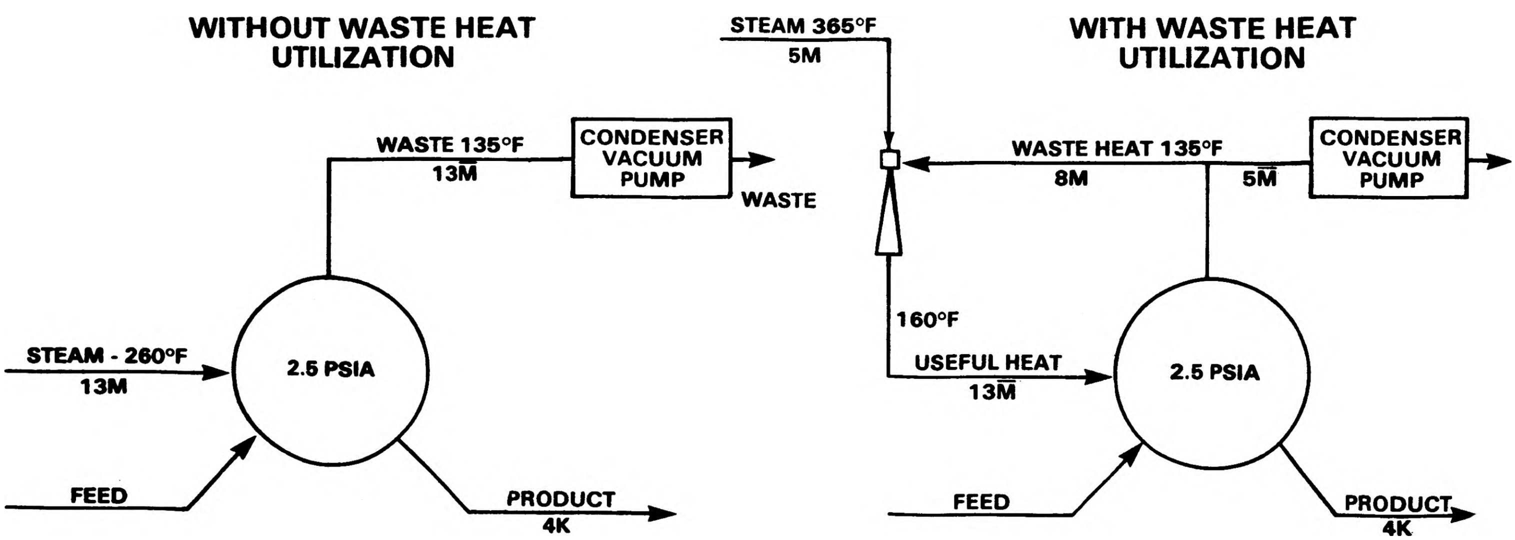

Figure 8B. Example 1: Application of waste heat utilization by boosting saturation temperature with thermocompressor.

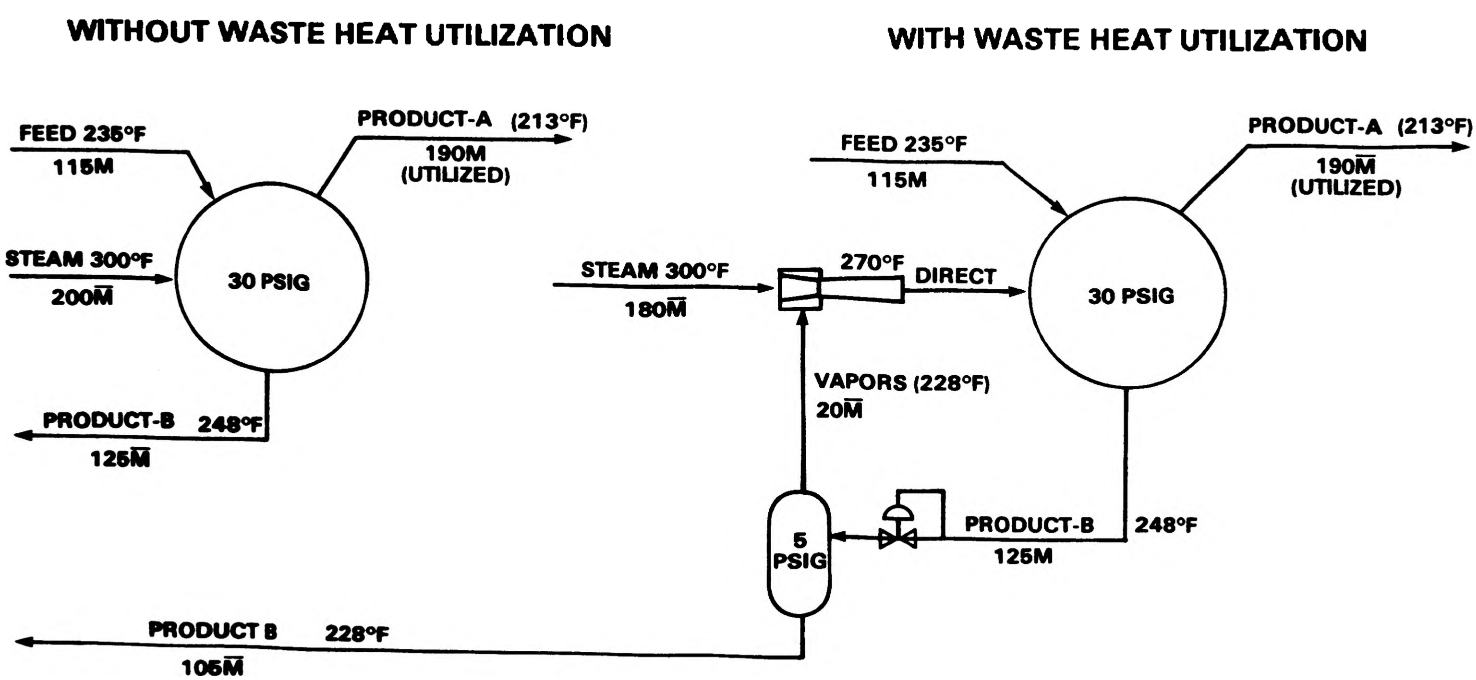

Figure 8C. Example 2: Application of waste heat utilization by boosting saturation temperature with thermocompressors.

Mechanical vapor compressors or heat pumps - When conditions are not right for a thermo-compressor, mechanical compressors or heat pumps could be used to boost the waste heat temperature to desired levels (see Figure 9A).

Unfortunately, due to high cost and maintenance of rotating equipment, mechanical compression for waste heat temperature boosting is not economically feasible for most applications at this time. One widely considered application is overhead vapor recompression in distillation proccesses. It is reported that this method has been used in Europe to some extent. However, our analysis of cost versus savings has shown that the cost of installation is still twice as expensive as we can justify for 10 M Btu/hr or more waste energy with 50 °F temperature boosting. This seems to be contrary to some of the claims that vapor recompression vendors are making. The main reason is that these vendors consistently underestimate the installation cost of a

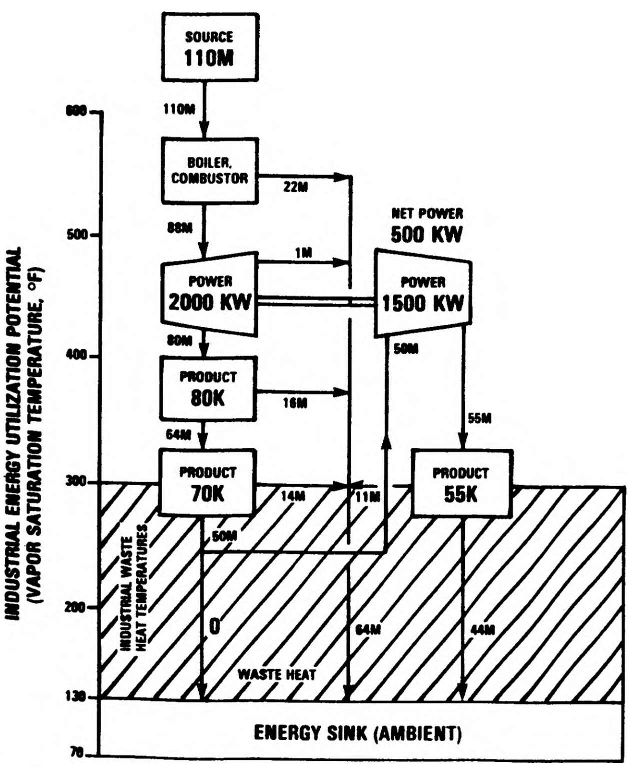

Figure 9A. Waste heat utilization by boosting saturation temperatures with mechanical compressors or heat pumps.

compressor in a process plant where there are more constraints and design guidelines to meet than the vendors consider in their analysis. Nevertheless, where the conditions are not severe, the vapor compression is becoming economically feasible for large scale applications. For example, in one of our plants we are considering generating low pressure steam with process wastes and compressing it to a useful level as shown in Fig. 9B.

One of the main reasons that mechanical vapor recompression has not been economical is that suitable standard compressors have not been developed by the industry. This has forced us to look at practically custom built compressors with very high initial cost. As the mechanical recompressors and heat pumps are becoming economically feasible, industry is starting to develop low cost standard compressors which will help to widen their applications.

Heat pumps are already well standardized. However, due to additional temperature boosting needed to provide the temperature differential required at the heat exchangers, they have not had wide use in industry. They are also limited at the high temperature end to 240 °F. Since industry needs higher temperature, the heat pumps are limited in scope of application.

CONCLUSION

Industry, especially the petrochemical industry, has large amounts of waste heat at 130 to 300 °F temperature levels. In the past, with relatively low energy prices, it has not been economically feasible to further utilize waste heat at these temperatures. As the energy costs increase, we are finding out that some techniques that require additional capital are becoming economically feasible. Utilization of waste heat at lower temperatures, and temperature boosting are two of these important techniques that are becoming eocnomically feasible. What we need to do now is to consider more of these techniques in our designs,

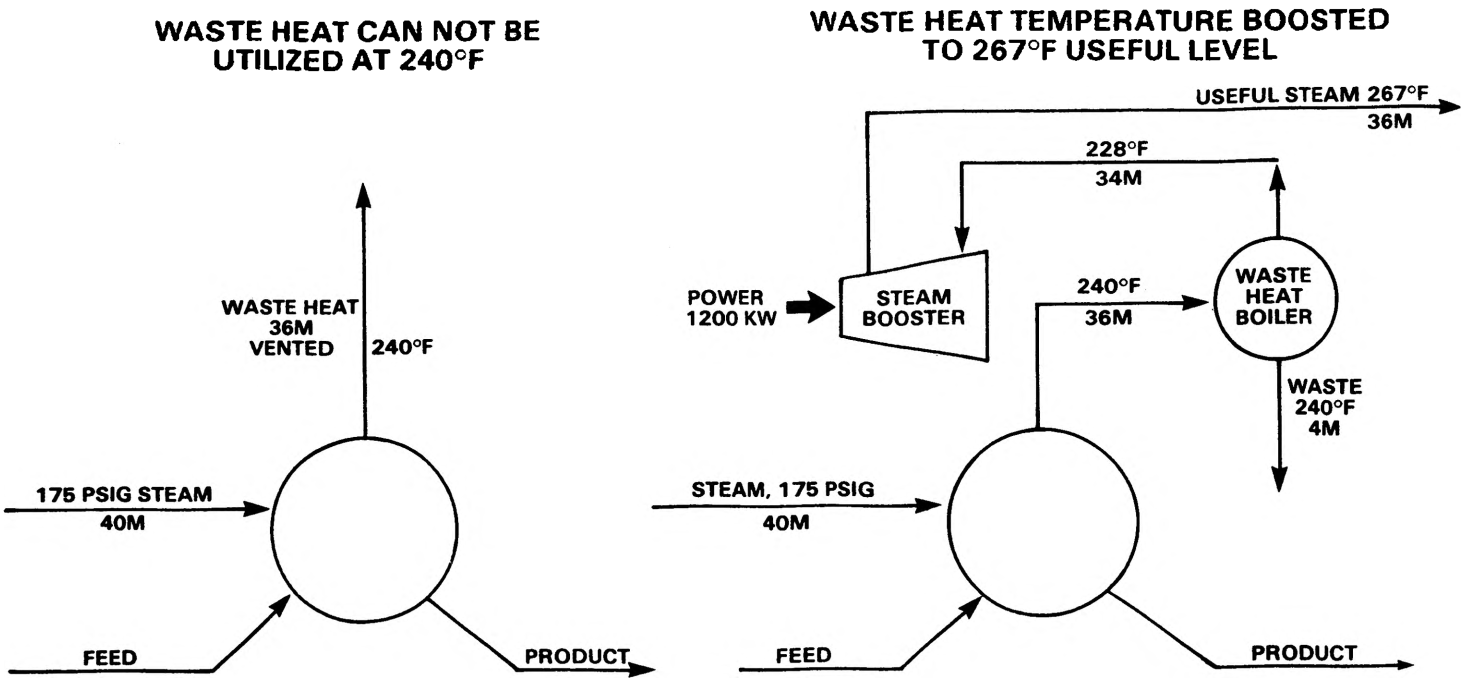

Figure 9B. Example: Proposed utilization of waste heat by boosting its saturation temperature with mechanical compressor.

even if they were uneconomical just a few years ago.

BIOGRAPHY

Mehmet Altin is an engineering specialist, process energy technology, in the Monsanto Corporate Engineering Department. His duties include carrying out energy conservation feasibility studies, reviewing capital projects for energy conservation opportunities, and providing technical assistance in determining and executing energy conservation opportunities. He has previously worked in design and start-up of industrial power plants and chemical process plants in U. S., England, and Turkey. Before joining Monsanto, he worked in an oil refinery, a shipyard, and at the University of Michigan.

He has received both his B.S. and M.S. degrees in Mechanical Engineering (Thermal Sciences) from the University of Michigan in 1968 and 1970, respectively.