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Waste Heat Recovery in Oklahoma Industry

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Abstract

There is presently a great deal of interest in renewable source or "free" energy. The U. S. Department of Energy recognizes waste heat as one of these renewable sources and much effort is being exercised to fully utilize waste heat capabilities.

Industry in Oklahoma has recognized the wealth of potential in waste heat recovery and has completed numerous projects in the area. This paper summarizes the major Oklahoma industrial waste heat projects. For each project, the objectives, results, and suggestions are given. Particular emphasis is given on cost effectiveness, evaluation and application to other industries.

Included in the study among others are companies that (1) use incinerator waste heat to generate low pressure steam for plant use, (2) use refrigeration waste heat for facility conditioning requirements, (3) use exhaust heat and a "heat wheel" to recover heat for conditioning requirements, and (4) recover waste heat from cooling water.

1. WHAT AND WHY

The well known EPIC book on Waste Heat Management (5) defines waste heat on page 1 as "heat which is generated in a process but then is 'dumped' to the environment even though it could still be reused for some useful and profitable purpose." Waste heat is normally sensible heat in the work that is hotter than ambient and is exhausted to the environment where it quickly degrades. Waste heat can often be put to very profitable additional use through preheating or other added work. This paper is an attempt to expose the field, discuss the potential, and present the results of a survey of Oklahoma industry to uncover the major usages of waste heat recovery.

There are many problems or hinderances opposing widespread adoption and utilization of waste heat by industry. Some of the major reasons are listed below with a short explanation.

(1) Waste heat is often diluted and of low temperature. Waste heat in a concentrated form as in furnace flue gasses is extremely useful; but waste heat in a diluted form as in quantities of cooling water heated to only 100°F or so can do little additional work without extensive upgrading (e.g., heat pumps).

(2) Waste heat recovery is sometimes difficult to justify economically. Artificial pricing of energy has made waste heat recovery energy more expensive than raw energy (but this is rapidly changing).

(3) Waste heat recovery technology knowledge is not widespread. Few managers are aware of the full potential of waste heat recovery and how to utilize the waste heat most profitably.

Waste heat can be classified into three temperature ranges as shown below (taken from EPIC (5)).

High	> 1200°F	capable of doing more work	Capable of steam generation
Medium	450°F → 1200°F		
Low	< 450°F	useful for preheating space heating or upgrading with heat pumps.	

As can be seen from the list above, high temperature waste heat is the most useful or adaptable but all ranges offer some potential application.

It is important to note here that waste heat recovery implies "wasted" heat not heat potential in wasted materials (e.g., incineration of waste paper or wood chips). Consequently, the paper concentrates only on wasted heat. The other is left for other articles.

The rest of this section discusses why waste heat should be recovered. Then, some techniques of recovery are presented. This is followed by a short section on waste heat recovery case studies around the country. Finally, the survey of waste heat recovery projects in Oklahoma industry is presented.

There are many reasons why waste heat should be recovered. First, it is good economics normally to obtain as much benefit as possible out of all our natural resources. Most importantly, however, the U. S. is already importing close to 50% of her petroleum needs. Waste heat recovery will help reduce this figure or at least keep it from climbing.

In four classes of industry alone (paper; food; stone, clay and glass; and primary metals), the potential is astounding. In 1975, they consumed about 7.7×10^{15} (7.7 Quads) Btu. The potential for waste heat recovery is estimated at 20% each. If 2/3 of the companies did this, the savings would have been about 1 quad per year or more than 400,000 barrels of petroleum per day. Industry consumes about 40% of the total U. S. consumption so the potential for all industry is even more impressive.

For each individual industrial manager the primary argument is that waste heat recovery can improve profits substantially, can reduce demand changes, and often can dramatically increase capacities. Paybacks of 1-3 years are common and of less than 1 year not unusual. Several companies have found that expansion plans were not feasible because of energy allotments but were able to expand anyway when waste heat recovery freed energy of the expansion. Other advantages include reduced size of equipment (more capacity or less capital cost), reduced maintenance (lower exhaust temperatures), improved pollution control, improved product quality, and improved public relations.

The evidence is almost overwhelming. Every manager should become aware of the vast potential and how waste heat recovery can aid in their operations. The next section discusses some of the techniques for recovery.

2. TECHNIQUES FOR WASTE HEAT RECOVERY

The technology behind waste heat recovery has been around for many years; but recently the maturing process has accelerated considerably. Several books and papers have been written on the subject; so this short paper cannot do very much justice to the subject. A short description will be given for each of several well-known techniques; but the interested reader should refer to the references for more detail. Finally, creativity is required for most projects. Many waste heat recovery applications are made with little engineering and a lot of "seat of the pants." While we don't encourage the lack of good engineering design we must admire the ingenuity of many of these applications.*

• Heat Wheels - Often called a "thermal wheel," the heat wheel is a rotating wheel of porous material that intersects 2 airstreams one of which is hotter than the other. As the wheel rotates, the wheel is heated on the hot side but subsequently cooled on the cool side. This way heat is transferred from the hot side to the cool side (or coolness is transferred the other way) without much cross contamination of the airstream. Figure 1 demonstrates this operation.

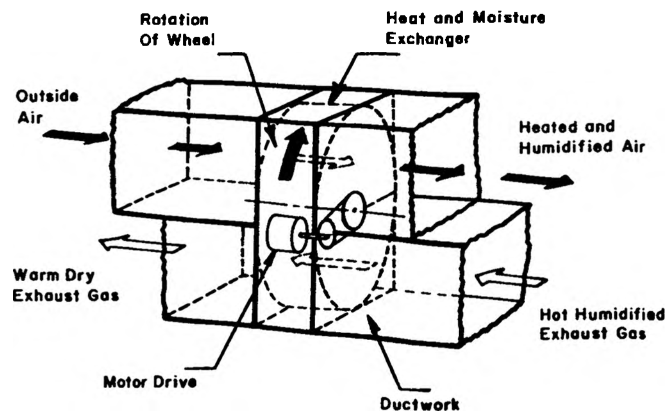

Figure 1. Heat Wheel

The heat wheel is particularly useful when a large ventilation requirement exists. The conditioned exhaust stream can be used to heat (or cool) the incoming make up air. Heat wheels can be designed to pick up latent heat (moisture) as well as the sensible heat and a purge section can be used to avoid cross contamination. Temperatures of up to 1600°F on the hot side have been used with experiments at even higher ones. Units are available commercially for 3,000 CFM (cubic feet per minute) up to 60,000 CFM. Efficiency in heat transfer of 60-80% for sensible and 20-60% for latent heat are common. Dubin, et al. (1) say that heat wheels cost $700-$1,000 per 1,000 CFM with 10% more for enthalpy recovery.

• Run Around Coil - This system consists of 2 or more heat exchangers (usually finned-coil affairs) connected by tubing. The heat transfer medium is usually ethylene glycol (to avoid freezing) although water may be used when freezing is not a problem. The heat exchangers are placed in the "hot" and "cold" streams and the transfer medium is pumped through the system accomplishing the necessary energy transfer. This operation is depicted in Figure 2.

The primary advantage to this system is that the "hot" and "cold" streams do not have to be adjacent making retrofit more of a possibility. Also, no cross contamination is possible and a run around coil system is less expensive than a heat wheel. Dubin et al (1) say that a run around coil system cost about 40% less than a heat wheel.

*In the following Figures 1, 3, 5, 6 and 7 were taken from Waste Heat Management Guidebook (5), and Figures 2 and 4 were taken from Energy Management Workshop (7).

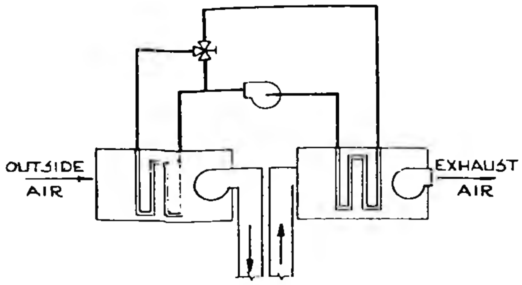

Figure 2. Round Around Coil

• Waste Heat Boiler - These are usually simple water tube boilers where hot flue gasses (from some external source) are passed over parallel tubes containing water. The resulting steam or hot water is collected in a drum for use. Auxiliary burners may be added as necessary to obtain the proper temperature. Figure 3 is a schematic of one waste heat boiler design. Waste heat boilers are used to recover energy from exhausts of gas turbines, incinerators, furnaces, and other equipment with relatively high exhaust temperatures.

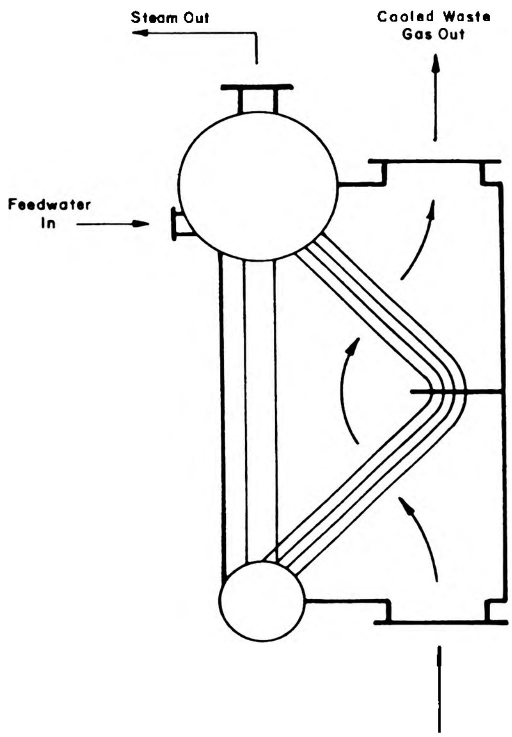

Figure 3. Waste Heat Boiler

• Heat Pipes - These systems use the latent heat of vaporization as the transfer mechanism. The exchanger is a collection of closed pipes each containing a material that vaporizes on the hot side forming a gas that migrates (thermally and gravitationally) to the cold side where condensation occurs. This condensation yields heat to the cold side and the transfer has occurred. The relatively cold liquid then migrates back to the hot side where the cycle begins anew. The operation is depicted in Figure 4.

Heat pipes are relatively efficient and maintenance free since there are no moving parts. Cross contamination is completely prohibitive. By changing the slope or inclination of the tubes, the amount of heat transferred can be controlled. They have been used in many areas including HVAC systems, waste steam reclamation, air preheaters, and various ovens and furnaces.

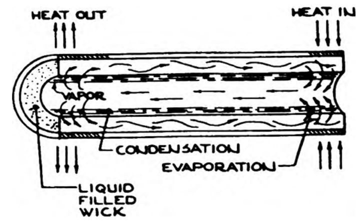

Figure 4. Heat Pipes

• Heat Pumps - Almost all the other techniques for waste heat recovery require relatively "hot" temperatures for proper utilization. The heat pump can take lower temperatures as available in cooling water and upgrade that heat to a level readily usable. The process is identical to that of a residential heat pump utilizing a compressor and an expansion device. The main advantage of a heat pump is that it can work with lower temperature sources and can provide heat with a relatively high efficiency or coefficient of performance.

• Recuperators - A recuperator is a relatively simple heat exchanger used for gas to gas heat transfer. Its purpose is to utilize waste flue gas heat to preheat combustion air being supplied to the burner. Savings in energy (and increased stack life due to lower temperatures) can be quantified as covered in EPIC (2) and they are substantial. There are many different designs such as the metallic radiation recuperator illustrated in Figure 5, tube convection types, ceramic, vertical tube-within-tube types, and various combinations. In this paper, the word "recuperator" will be used for any device designed to preheat combustion air with waste flue gasses.

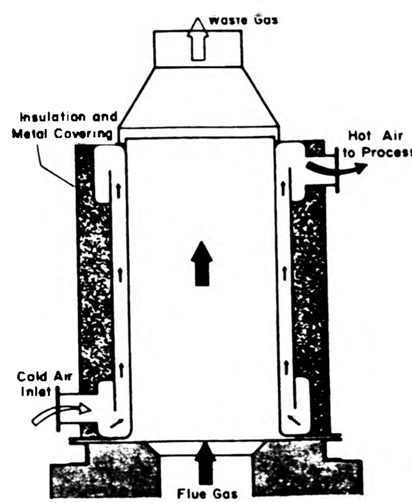

Figure 5. Metallic Radiation Recuperator

Variations in design of recuperators are numerous. For example, flow may be counter instead of parallel as shown in Figure 5. Combinations of various types may be tried, different materials may be utilized (ceramic units now theoretically allow operation up to 2800°F on the "hot" side and 2200°F on the cool side), etc. Their utilization may require the purchase of other equipment to allow for modulations in recuperator operation, higher temperatures coming into the burners, and other conditions.

• Air Preheaters - Similar in design and concept to recuperators are the air preheaters which are designed to recover waste heat in low to medium temperature flue gasses. In general, these units use the heated air directly so no contamination is allowed. Figure 6 is one possible design. They usually occupy considerable space and are expensive but the mechanical maintenance is simplified over most alternative ideas.

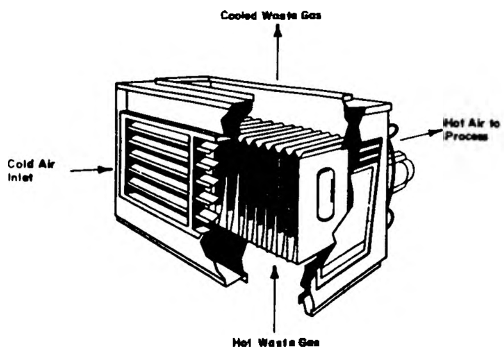

Figure 6. Air Preheater

• Liquid Preheaters - When the material to be preheated is liquid in nature, different designs are needed. For a gas to liquid transfer as in hot flue gasses to water for various purposes, a finned tube affair with the liquid in the tube is normally used as illustrated in Figure 7. The most common of these is the use of boiler flue gasses to preheat the boiler feed water. This application is generally known as an "economizer." In the rest of this paper, the word "economizer" will refer to a boiler application where flue gasses are used to preheat the boiler feed water. Liquid preheaters can also be used for domestic hot water, space heating, and heating process liquids.

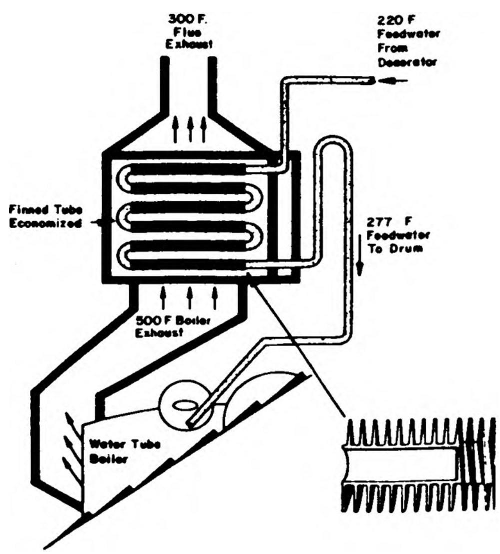

Figure 7. Liquid Preheater (Economizer)

When the waste heat is contained also in a liquid, a different design is necessary. Usually, a shell and tube affair is utilized. Applications include waste heat from refrigeration, condensate from process steam, coolants from furnace doors, engines, air compressors, bearings, etc.

• Others - There are numerous other methods of waste heat recovery that are not covered here. Some of these such as condensate return have been utilized for years for waste heat and treated water recovery and are very familiar to most. Others such as cogeneration are relatively new and are being developed rapidly. This article simply could not cover all them. Some "others" are:

(1) Boiler condensate return
(2) Reflashing of condensate to lower pressure steam
(3) Numerous methods of cogeneration
(4) Heat of light recovery
 (a) Utilizing air through lighting fixtures
 (b) Utilizing liquid through the fixtures
(5) Various HVAC combinations
 (a) Double bundled condensers
 (b) Closed circuit heat pumps

For an explanation of most of these and others, see the various references in the Bibliography.

As a summary to the "techniques" section of this paper and to tie the material together, Figure 8, taken from Waste Heat Management Guidebook (5), shows each of the types discussed and their respective applications. Dubin, et al. (1) (pages 518-521) present a summary of locations of waste heat and various suggested ways of recovering it. Design parameters are recommended with estimated costs.

Commercial Heat Transfer Equipment \ Specifications for Waste Recovery Unit	Low Temperature Sub-Zero - 250°F	Intermediate Temp. 250°F - 1200°F	High Temperature 1200°F - 2000°F	Recovers Moisture	Large Temperature Differentials Permitted	Packaged Units Available	Can Be Retrofit	No Cross-Contamination	Compact Size	Gas-to-Gas Heat Exchange	Gas-to-Liquid Heat Exchanger	Liquid-to-Liquid Heat Exchanger	Corrosive Gases Permitted with Special Construction
Radiation Recuperator			●		●	1	●	●		●			●
Convection Recuperator		●	●		●	●	●	●		●			●
Metallic Heat Wheel	●	●		2		●	●	3	●	●			●
Hygroscopic Heat Wheel	●			●		●	●	3	●	●			
Ceramic Heat Wheel		●	●		●	●	●		●	●			●
Passive Regenerator	●	●			●	●	●	●		●			●
Finned-Tube Heat Exchanger	●	●			●	●	●	●	●		●		4
Tube Shell-and-Tube Exchanger	●	●			●	●	●	●	●		●	●	
Waste Heat Boilers	●	●				●	●	●			●		4
Heat Pipes	●	●			5	●	●	●	●	●			●

1. Off-the-shelf items available in small capacities only.
2. Controversial subject. Some authorities claim moisture recovery. Do not advise depending on it.
3. With a purge section added, cross-contamination can be limited to less than 1% by mass.
4. Can be constructed of corrosion-resistant materials, but consider possible extensive damage to equipment caused by leaks or tube ruptures.
5. Allowable temperatures and temperature differential limited by the phase equilibrium properties of the internal fluid.

Figure 8. Applications of Heat Exchangers In Waste Heat Recovery

3. CASE STUDIES (NATIONAL)

Below is a survey of some of the examples appearing in the references of waste heat recovery using the techniques presented in this paper. The survey of Oklahoma industry is presented later in more depty. No attempt is made to provide all details. Instead, only enough is proved to orient the reader and to help the serious manager find more information. For this latter purpose, each case study is indexed (at the end of the description) with the appropriate reference number from the Bibliography and page number. For example, "5, page 57," means more information can be found in Waste Heat Management Guidebook on page 57.

Finally, the case studies are grouped by subject matter to facilitate reading. Groupings include (1) Recuperator (Preheating Combustion Air), (2) Preheating process feed stocks, (3) Preheating make up air, (4) Economizer (preheating boiler feed water), (5) Process Reuse (misc.).

3.1 RECUPERATORS

(1) A glass company rebuilt one of its clay tanks to include a recuperator in the stack. Over 60,000 $ft.^3$ of natural gas was saved with an undiscounted payback of 1.53 years** (5, page 57).

(2) A metallic radiation recuperator was installed on a small rotary forge furnace. The first cost was paid back in 3.2 years (5, page 62).

(3) A manufacturer of furnaces installed two identical furnaces - one with a recuperator and one without. Tests showed the recuperator saves 29% of the gas as fuel on full fire and 14% on idle. Payback worked out to be 4.6 years. (5, page 138).

(4) A recuperator installed on a glass furnace saved 23.3% of the natural gas or $7,123 annually with a first cost of $17,244, payback is 2.4 years (9).

3.2 PREHEATED PROCESS FEED STOCKS OR REUSE IN PROCESS

(5) A gas company uses exhaust gas from a gas turbine to preheat regeneration natural gas. A finned tube system in the exhaust stream accomplishes the heat transfer. Payback was 2.75 years (5, page 68).

(6) An incinerator was added to flash solvents from a bake process in a large can company. A heat exchanger was added to the exhaust to preheat the "dirty air" coming in - 54% of the fuel for the incinerator was saved yielding a 5 year payback in 1970. (It would be much quicker now.) (5, page 74).

(7) A citrus fruit processor utilizes waste heat from a dryer in a molasses evaporator. Although the first cost was $780,000, the payback was 5.2 years based on 1975 fuel cost. (5, page 98).

(8) A heat wheel uses flue gasses from a furnace to preheat solvent laden air before going to an incinerator. The heat wheel operates in temperatures of 1200-1600° and is 72% efficient. Payback was 1.5 years. (5, page 132).

(9) A conventional muffler on a 500 hp gas engine was replaced with a waste heat recovery muffler to generate process steam. The system cost $20,000 yielding savings of $13,900 per year. Payback is 1.44 years (3, page 3-39).

3.3 MAKE UP AIR PREHEATING

(10) A finned tube heat exchanger in a boiler stack is used to provide heat for a warehouse. Excess heat is used to preheat boiler make up water (no condensate return so savings were large). Payback was 2 years (5, page 84) (3, page 3-37).

(11) A glove manufacturer had to change air every 2 1/2 minutes for naptha fume control. A heat pipe system was installed in the exhaust air stream (94°F) to preheat the make up air. Payback was about 3 years but most importantly, the "freed up" gas allowed a previously impossible expansion. The heat pipe is 62% efficient. (5, page 78).

(12) A dental products plant uses exhaust from a paint room (including ovens) and a heat wheel to heat the make up air. No first cost figures are given but the system saved $14,000 in heating cost. (5, page 128).

3.4 ECONOMIZERS

(13) An economizer was retrofitted to a boiler where 80% of the steam produced was used in the process and 20% for building heat. Condensate return was about 98%. Payback was less than 1 year. (5, page 90).

3.5 HOT WATER PREHEATING

(14) Seam welding cooling water was used as a source of heat for an industrial heat pump which freed up a gas boiler. Heat storage capability was built in to avoid usage during peak demand periods. The final operating cost was slightly more than for gas but the gas was freed for other purposes. Other sources of cooling water include extruders, injection molding, refrigeration equipment, and arc welding. (5, page 120).

(15) A restaurant used waste heat from air-conditioning equipment to help in water heating through a tube in tube exchanger installed in the refrigeration hot gases. Payback was 2.9 years. (5, page 112).

3.6 PROCESS STEAM

(16) An asphalt plant uses a waste heat boiler and hot flue gases from a pollution control incinerator to generate low pressure steam.

**We recommend the use of internal rate of return with complete tax analysis for economic justification studies. However, the purpose here is not to cover economic analysis, so the more popular "undiscounted payback" is used.

Payback was less than one year. (5, page 106).

4. CASE STUDIES (OKLAHOMA SURVEY)

Following is a survey of waste heat recovery in Oklahoma industry. It is by no means an exhaustive survey but it does cover several hundred industries of widely varying character. This summary is intended to expose a wide variety of waste heat recovery applications and hopefully stir some creative ideas in the readers. Further information on each can be obtained from the authors in most cases. Each case study is presented in more depth than the previous ones. When possible, economic data is presented. Often, however, for various reasons the economic data was not available.

4.1 A large tire manufacturer has three boilers installed 1970, 1972 and 1975 each rated at 50,000 pph. Economizers were included with each originally. The last economizer cost $21,000 in 1975 and it increased boiler efficiency by 4.6%. Boiler feed water enters the economizer at 228°F and enters the boiler at 297°F. During the past six years, the boiler economizers have attributed to the savings of 172 billion BTU and $160,000 in fuel cost. The payback period on the last economizer was one year.

4.2 The same tire manufacturer collects waste condensate which has been contaminated in the tire curing process. The condensate is collected in a large underground pit into which a heat exchanger was suspended. The soft water make up is passed through this exchanger increasing its temperature by 10°F. Savings are 2.5 billion BTU's or $4,000 in fuel costs annually.

4.3 A large chemical processing plant uses a recuperator to recover heat from flue gases to preheat combustion air used in a chemical reformer.

4.4 The same chemical plant uses economizers on all their boilers. The main boiler produces 600,000 lbs/hr at 1,500 psi.

4.5 All of the state's utilities utilize waste heat recovery in various ways. For example, one uses gas turbine exhaust to preheat boiler feed water (installed in 1947). In another application, the exhaust from the gas turbine is used directly (with supplemental firing) in a conventional boiler.

4.6 A large relatively new university in the state uses gas turbines to generate power for the campus. The exhaust gas from these turbines is used in seven 200 hp waste heat boilers. The resulting low pressure steam is used throughout the university and is used to heat water. The system was installed in 1968. Savings in fuel and electricity costs are in excess of $260,000 per year.

4.7 Another large university has incorporated waste heat recovery in several areas of the steam system. Recuperators are used on all boilers. In addition, a heat exchanger in the continuous blowdown and deaerator system preheats the make up water. Finally exhaust from a gas turbine is used to generate low pressure steam which is used to heat the campus.

4.8 A U.S. Government facility in Oklahoma is very energy conscious with an active energy conservation program underway. In addition to a solar system for heating water, it has added a heat pipe type recuperator to one of their boilers. Savings in fuel consumption run about 7% over all operating ranges. Incoming combustion air is preheated to 250°F. The system cost approximately $11,343 including indirect costs and generated a two year payback. The system is shown schematically in Figure 9.

4.9 A medical school in the state installed a heat wheel. It is nine feet in diameter and 24 inches wide. The unit consists of a supply and exhaust fan and media. The media is made of prefilters, carbon tray after filters, and aluminum oxide mesh which aids in recovering sensible and latent heat. Under design cooling conditions, the wheel reduces outside air from 100°F to 85.8°F (Dry). Further cooling brings this down to 55.5°F. 22,000 - 30,000 CFM are handled. Fuel consumption was decreased 27% for a savings of $7,500 per year in fuel cost. Payback was about five years.

4.10 Another tire manufacturer has an extensive energy management program underway. A heat exchanger was installed in three locations to recover wasted heat. In these, excess steam from the curing press was exhausted to the atmosphere. The steam now preheats make up water for a contact heater. The water is heated from 180°F to 250°F. Projected savings are 12,665 KCF of gas and 13.2 billion BTU. The condensate is also now returned to the boilers. Payback for the $20,000 investment was 21 days.

4.11 A large milling company in Oklahoma uses heat recovery from a 200 hp boiler to help heat the plant. A gas to gas exchanger in the boiler stack provides heat to the make up air being supplied to the plant.

4.12 Another tire manufacturer in a new plant being built in Oklahoma identified and used waste heat recovery in several locations. They are:

(a) Economizers are installed on the boilers. A typical one cost them $121,800 and yielded a payback of 2.2 years.

(b) A heat exchanger for blowdown heat recovery cost $4,500 yielding a .6 year payback.

(c) White side wall paint drying air is recycled for further use.

4.13 An asphalt plant in Oklahoma utilizes waste heat from a pollution incinerator to generate steam in a waste heat boiler. Excess steam is generated. Very favorable payback is reported.

4.14 A medium sized grocery store (about 12,000 ft.) uses waste heat from refrigeration to supply heat to its space heating system. The hot gases go directly to the return air line where a fin tube affair accomplishes the heat transfer. Virtually no supplemental heat is required. (Most large grocery store chains use this system or something similar now.)

4.15 Another large firm uses cooling water from 60 hp compressors as make up water for their boilers.

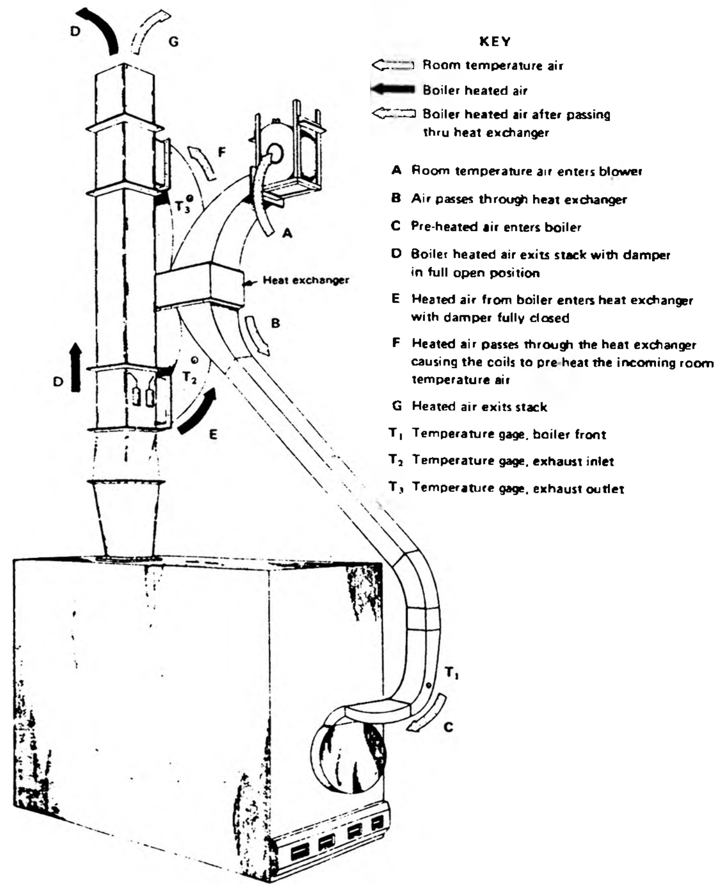

Figure 9. Heat Pipe Recuperator

SUMMARY CONCLUSIONS

This paper demonstrates that the potential for waste heat recovery in manufacturing operations is substantial and the economics are favorable with an even more favorable trend. Finally, the technology is fairly mature even if not widespread. Numerous case studies from the U.S. as a whole and Oklahoma specifically are presented.

It seems that waste heat recovery in boiler operations is mature and wide spread with very favorable economics. Other applications appear less frequently but larger, more progressive companies are beginning to uncover more opportunities. Preheating of make up air with heat pipes, run around coils, or heat wheels seems to be rapidly maturing.

The authors invite comments on the paper and ask for contributions so the paper can be more complete. Details on many of the case studies presented can be provided by the authors.

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(6) Agrico Chemical at Verdigris
(7) Oklahoma College of Osteopathic Medicine and Surgery
(8) Dayton Tire and Rubber Company of Oklahoma City
(9) Allied Material Corporation of Oklahoma City
(10) Shawnee Milling Company
(11) Weddle Food Stores of Muskogee
(12) Goodyear Tire and Rubber Company of Lawton

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BIOGRAPHICAL SKETCH

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James M. Phillips - Mr. Phillips is currently a graduate student in Industrial Engineering at Oklahoma State University. He has worked in the steel and rubber industry as well as serving two years with the United States Peace Corps in Kenya, East Africa. He has given numerous talks and papers on energy management and has conducted several conferences in the area. His current research includes Energy Audits and Energy Management.