BACK TO EARTH AND REAL BIG BUSINESS: HEAT PIPES FROM SATELLITES AND MICROCHIPS TO INDUSTRY

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Abstract

Heat pipe research and its applications seem to be much more attached to space exploration and microelectronics than other conventional uses. Evaluating this scenario, some actual and measurable opportunities for utilization of heat pipes in industry are listed, including selection of better spots and advantages for its usage. Potential achievable gains, barriers and some suggestions to accomplish this goal are presented.

KEYWORDS

Heat pipe, thermosyphon, energy efficiency, energy conservation, industrial usage, heat recovery.

INTRODUCTION

Heat pipe and thermosyphon technologies share some basic operating principles but were developed in different times, with different basic purposes, at least in the beginning.

Thermosyphon was developed in dawn of the nineteenth century during speeding up years of Industrial Revolution. It aimed at its birth, industrial usages like steam generation and steam machines. Later, a little by chance, it moved to baking apparatus like bread and food for the military during war period. Exception for some proposed applications on patents required, this development rested for many years almost without further application. Heat pipe on the other hand, was developed in the second half of the twentieth century, based on the same principles. But it aimed to solve a specific problem, cooling metal parts exposed to Sun during space exploration. The way to promote heating transfer in zero gravity by a simple and unmanned device at a reasonable cost was enhancing thermosyphon with a porous media and then you got heat pipe. Miniaturization era and higher density transistors – or better microchips – also began to demand heat transfer in a similar mood. With Earth gravity, of course, but with various geometrical shapes and positions, with lesser and lesser dimensions. And again heat pipe came, saw and conquered [1].

But this history left a legate on generations of researchers. Since heat pipe became a piece so important in spacecraft as the astronauts and so vital to microcomputing as the operating system, more and more money showered over research centers and universities from enterprises eager to have “the best” and “state of art” developments. No, no exaggeration. Without heat pipes many of the so fundamental “gizmos” needed to guarantee a safe space travel would not work and without these, what astronauts are needed for? On the same fashion, without heat pipes to assure the proper working temperature for your CPU, the basic tests in your computer will not allow it to run and again, who needs Windows? Well, all that money moved a lot of teachers, students and researchers to work around these knowledge themes. Is that really so? To check this mere impression or feeling a little test was performed with internet assistance. An Internet search tool and successive matching queries were used to answer some questions like:

a) How many times heat pipe is refereed?
b) How many times it is linked to one of these previously mentioned themes – space exploration and microcomputing?
c) How many times it occurs altogether with industrial devices?
d) Which language sites it occurs?
e) Where it occurs in the World? (these last questions came as a consequence of the search).

First it is assumed that this is not a highly scientific and broadening method for a lot of reasons and a few are listed bellow:

- Not all scientific and technical production is available on the net.
- There is a good chance that many sites are repetitions of another one or basically tell the same story.
- Also there are many sites that deal with a fairly vast range of diverse subjects and by chance totally different topics may appear correlated.
- Using terms only in English all other occurrences in equivalent terms translated will be missed – this is specially significant considering ideographic languages like Japanese, Korean, Chinese and other Far East languages.
- Some select terms may have different meaning depending on context.
- Internet search tools may not be as exhaustive and accurate as we might wish them to be.

But please, be kind, this is not to prove a daring scientific hypothesis; it is just to support a point of view. In order to accomplish this test two approaches were made– positive and negative – that means:

- In positive approach, it will be searched occurrences of "heat pipe" with another significant word like "satellite" – this is to devise how many documents or pages appear with these two terms.
- In negative approach, it will be searched occurrences of "heat pipe" without the same other significant word – this to refuse documents where both words appear.

Considering the basic search accessed on July 23, 2008, "heatpipe" or "heat pipe" appeared by 3.990.000 times. Whatever approach, when the search includes or excludes a term it will produce less occurrences because it is restricting the sample. This will be interpreted as follows – if heat pipe plus a term gives a number closer to the total occurrences of heat pipe alone, more likely, they are strongly related. Also, heat pipe less the same term resulting a quantity of occurrences much lower than the original plain search for heat pipe, will also mean a strong relation between them. On contrary, heat pipe plus the term with a low number of matches or heat pipe minus the term with a high number of matches, will mean a weak link. Using these approaches and a sequence of successive searches, a comparison among the occurrence numbers will reveal some tendencies.

The following terms were selected to make the matches with "heat pipe" and they are related to some of our main topics:

- Microelectronics – chip; computer; cooler; CPU and electronics.
- Space exploration – Satellite and space.
- General industry – boiler; condenser; exchanger; furnace; heat exchanger; industry; oven; recovery; refinery and steam.

One may notice that the list for industry has more terms than others, but this is on purpose. Results of the searches are shown in Table 1.

With all possible flaws that this method may present it is clear to see, that at least on the internet, heat pipe is much more likely associated to subjects related to microelectronics and space exploration, because:

1. Positive matching results higher occurrences with terms related to microelectronics and space than industry related terms - twice to even ten times higher.
2. Negative matching of terms related to microelectronics and space reduces more the number of occurrences than industry terms.

Table 1. Heat pipe plus/minus other terms

negative	**Heat pipe**	**positive**
1.750.000	chip	480.000
1.490.000	computer	749.000
1.150.000	cooler	1.510.000
1.100.000	CPU	232.000
1.870.000	electronics	212.000

1.970.000	satellite	125.000
1.910.000	space	207.000
2.130.000	boiler	15.200
2.130.000	condenser	27.400
2.130.000	exchanger	99.400
2.130.000	furnace	13.400
2.130.000	heat exchanger	43.600
1.980.000	industry	73.300
2.130.000	oven	11.100
1.740.000	recovery	62.800
2.120.000	refinery	1.720
2.030.000	steam	38.900

As accessed July 22, 2008

Even though counting with a higher chance of coincidence than the other topics – simply because more terms were listed - correlation between heat pipe and industry seems to be very poor, compared with the universe of “heat pipe” occurrences. As a matter of fact the more specific, the lower the coincidence as in case of “refinery” that appears only 1.720 times together with “heat pipe” merely 0,04% of this word internet appearances.

And in which languages do these people that concern about heat pipe communicate? Again, just restricting some languages over that search that gave 3.990.000 matches, the results are expressed on Table 2, where the sum of this sample adds 2.727.900 occurrences (68,4% of 3.990.000).

Table 2. Heat pipe occurrences concerning language sites

Language	**Occurrences**
English	886.000
German	421.000
Check	348.000
French	256.000
Hebrew	168.000
Polish	158.000
Hungarian	131.000
Italian	88.300
Slovakian	60.000
Romanian	47.400
Spanish	44.100
Norwegian	37.600
Russian	33.700
Portuguese	25.800
Chinese simplified or traditional	23.000

And also the following question came easily, where in the World people discuss heat pipe? Again just restricting countries, results on Table 3.

Table 3. Heat pipe occurrences concerning countries

Country	**Occurrences**	**% total heat pipe**	**% accum.**
USA	436.000	10,9	10,9
Germany	419.000	10,5	21,4
Check Republic	333.000	8,3	29,8

France	240.000	6,0	35,8
Israel	173.000	4,3	40,1
Poland	110.000	2,8	42,9
Hungary	93.500	2,3	45,2
Italy	87.200	2,2	47,4
United Kingdom	69.800	1,7	49,2
Ukraine	55.900	1,4	50,6
Slovakia	52.900	1,3	51,9
Rumania	49.700	1,2	53,1
Turkey	49.500	1,2	54,4
Canada	45.200	1,1	55,5
Norway	38.900	1,0	56,5
Finland	36.500	0,9	57,4
Austria	31.600	0,8	58,2
Netherlands	29.800	0,7	58,9
Russia	28.800	0,7	59,7
Sweden	28.200	0,7	60,4
Spain	26.000	0,7	61,0
Australia	22.600	0,6	61,6
Switzerland	16.500	0,4	62,0
China	15.500	0,4	62,4
Brazil	14.800	0,4	62,8
South Korea	14.600	0,4	63,1

This inevitably takes us to some inferences. For instance, it is most likely that a researcher or technician that is interested in heat pipe technology ought to be in North America or in Europe and communicates preferentially in a language from European origin. But, somehow supporting that previous impression; it seems that most of them are more attached to heat pipe usages in outer space and in the micro world.

But there are a lot of opportunities for heat pipe utilization, back on Earth and with the big sized things especially in the industry. That is the goal of this text, reviewing in more detail some of these ideas.

INDUSTRIAL ENERGY DEMAND IN A BROADENING VIEW

Industry in general is a heavy energy consumer. Like an immense Carnot engine, receives tremendous amounts of energy as input, uses it as work to transform materials and outputs almost the same amount of energy exception for the quantity that was transferred to the main product during transformation process. One small detail. This enormous energy reject is somehow degraded in some qualities that make it useless for most processes that received the initial input. And basically this reject is HEAT in a temperature too low to allow its use back in the process, but in other hand too high to be just returned to environment. And that is where all problems lie. There is a reasonable amount of energy available that has no use at that temperature, but if you simply throw it away, it will be too costly, because of energy costs and environmental issues. Also it is not only one process, there ought to be a lot of them, scattered around, rejecting energy at different temperatures and rates.

Is there a way to try to use this energy better? Yes, there is, it is called Process Integration, uses some specific methodologies like Pinch technology. It maybe used with a daring and innovative view providing a intense integration and dependency between very diverse processes and achieving an optimized energy efficiency operation point thru higher investment and low operating costs. Or it might be applied in a more conservative view, promoting more independency between processes, obtaining reasonable energy efficiency with average investments and not so low operating costs. Whatever option, it will demand in the end of design two energy flow requirements, a hot and a cold utility. Both will have to comply with processes major and minor temperatures requirements and these two will work as a kind of exchange currency of energy thru all the plant. The hot utility will be usually obtained from direct fuel burning or from steam and the cold, normally water. But why water and steam?

Water is considered to be a fairly available, low cost and harmless fluid. And steam, water with high energy content, has two amazing characteristics concerning energy flow:

- Allows heat transfer at constant temperature – this quality reduces heat exchanger area and hence reduces investment costs and also.
- Allows energy conversion from heat to work – simply provides the actual way to manage energy use.

Not forgetting to mention the possibility to obtain a precise temperature by simple pressure control, thanks to thermodynamics qualities and Mollier curve. Also, possible reuse by condensation and return to boiler, either a fired or heat recovery one and some others good characteristics that are less significant at this point. Cooling with water is a fine option because by simple atmospheric evaporation you can restore the low temperature needed to the cold utility.

Pretty good, right? The perfect medium, non toxic, with exceptional thermodynamic properties, who could ask for more? Sorry, nothing comes for free. The adoption of a steam system and a cooling water cycle demands a lot of companions and of course costs and some misfits.

Water either for hot or cold utility requires treatment. Previous, to provide quality that guarantees proper endurance of all steel equipment involved in the process like boilers, steam pipes, exchangers, valves etc. And effluent treatment in order to prevent discharging in environment harmful and toxic materials like oils, heavy metals etc. Both kinds of treatment will demand investments in equipments, operational costs due to chemicals, personnel, materials and more energy. And maintenance. Since the population of equipments has multiplied due to all these ancillary systems, so sorry again, you will have more things to take care of, break, fix, check, refill, lubricate, paint. In addition, more spare parts, that means stocks, including physical area to keep the parts properly, personnel to take care of it and money, yes money. Spare parts are actually money in form of potential assets, but in the end of the day, they are fixed money, or worse, financial costs. It is money that is not currency anymore, but must return the same interest otherwise, the company is loosing.

And let’s not skip the losses! Thermodynamics 2nd Law provides us rules about unavoidable losses in energy conversion and distribution systems. With these we include heat to atmosphere thru insulation over pipes and boiler surfaces, fuel burning, stack gas heat etc. But there are other ones you have to get used to like steam leaks, fugitive steam thru steam traps, water leaks and so forth. More maintenance, personnel, materials, controls, more money! And to increase the mess, take all this aspects together bringing hazard to working environment. Steam leaks are noisy and potentially harmful. More equipment in the facility, more maintenance, more chances of an eventual accident. Handling chemicals, that many times are poisons or carcinogenic also does not help, either.

Quite a complicated world! But what are the numbers involved and where do heat pipes fit on this mess? One thing after the other. First the numbers.

Process heating accounts for about 36% of the total energy used in industrial manufacturing applications, while steam systems account for other 30%. These figures vary depending on the specific industry and process. Fig. 1 shows and schematic view of U.S. Manufacturing Industry Energy Balance as a whole by 2004.

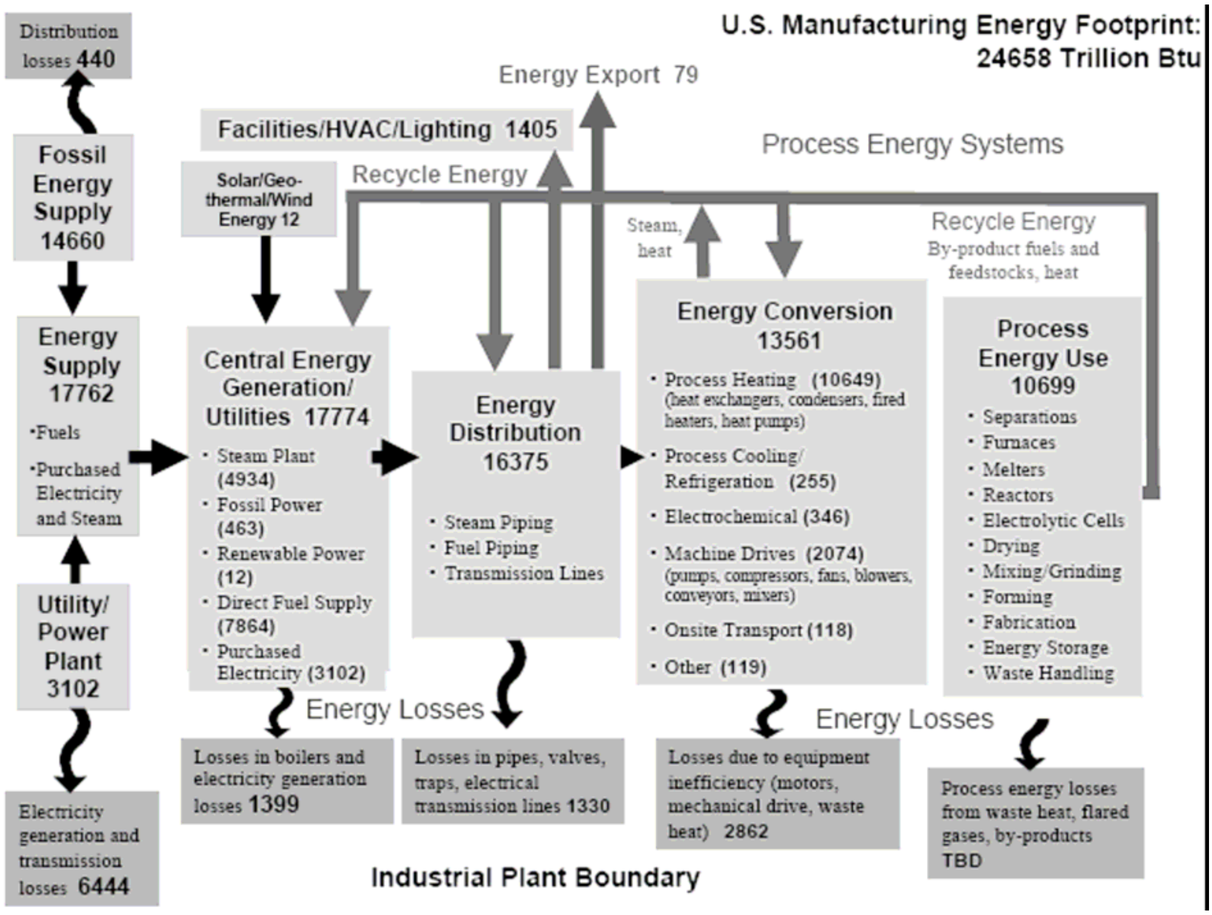

Fig. 1. U.S. Manufacturing Energy Footprint [2]

This picture shows that US manufacturing industry uses 44% of its energy requirements in core process and 20% goes to steam, while a significant amount is recycled as heat and goes to losses that maybe reach 30% of total input. Taking a closer look at these losses on Fig.2 and 3, it is clear to see that the share of usual losses over heat and steam is highly significant. On site losses with energy conversion and distribution may go up to 26% of total energy demand while losses due to steam system generation and distribution can add to 45% of the energy dedicated to this purpose.

So there are opportunities to make these systems more efficient throughout industry that could reduce annual plant energy costs by several billion dollars or euros. And since heat and consequently steam are produced by fuel burning correspondent environmental emissions of millions of metric tons of CO_2 could be avoided.

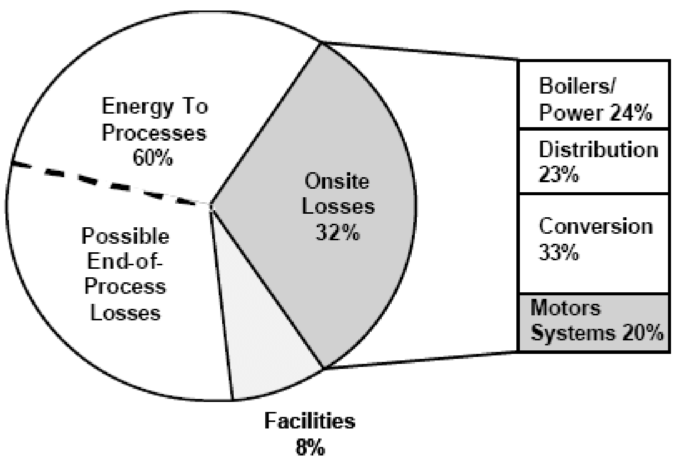

Fig. 2. Onsite Energy Loss Profile for U.S. Manufacturing and Mining Sector [2]

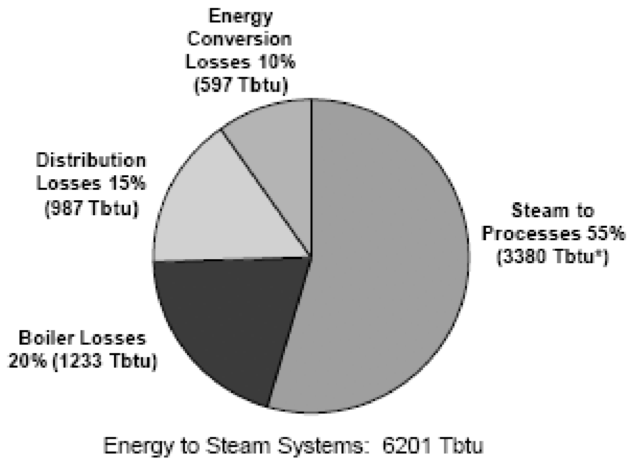

Fig. 3. Steam Use and Losses in Manufacturing and Mining [2]

So much for the numbers, but what is there for heat pipe application?

POTENTIAL INDUSTRIAL HEATPIPE APPLICATIONS

Back to basic design assumptions on heat pipes, they were a way to promote heating transfer by a simple and unmanned device at a reasonable cost. Heat pipes should be applied in the industry with this same approach. Well-designed heat pipes can provide heat transfer without many of the regular ancillary systems and misfits that energy distribution systems like steam bring together. For instance, since all necessary fluid to perform heat transferring1 process is confined inside the heat pipe itself, no previous treatment or effluent treatment will be demanded. Without that, you can count out some chemicals, personnel, materials and energy, which means lower operational costs. In the specific case of steam, since there will be less steam circulating, it is likely that somewhere in the plant less fuel will be burned and again less atmospheric emissions. Less steam, fewer steam pipes, valves, steam traps, insulation, steam leaks, less losses and less hazards. Therefore, less heat going in implies and less heat out, so cooling systems maybe diminished. Fewer equipments, less maintenance, fewer spare parts. This leads to lower investments and even lower operational costs.

Figure 4 shows a generic process heating system and from that, it is concluded that main potential applications for heat pipe technology lie on heat transfer from combustion to process and waste heat recovery. Besides steam, there are some others.

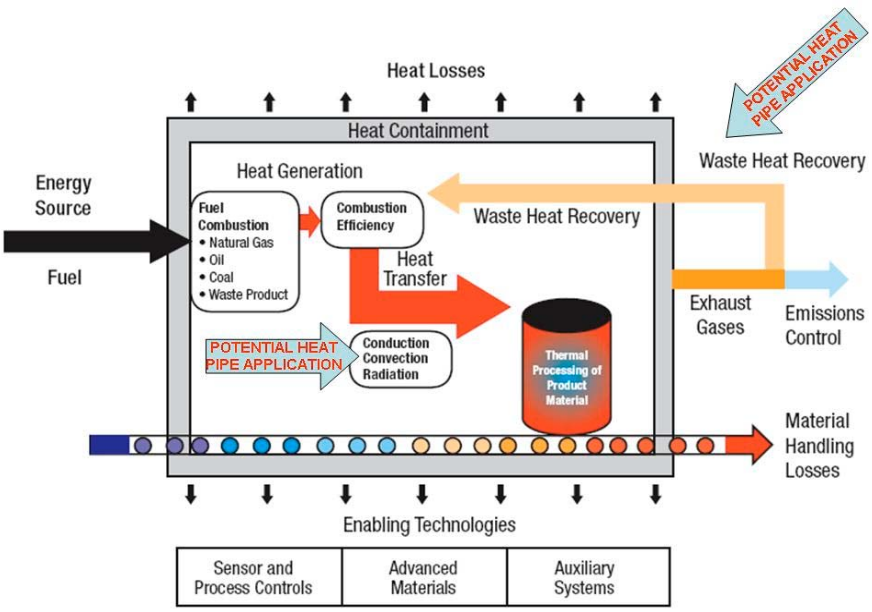

Fig. 4. Process heating system and opportunities for heat pipes. Adapted from [3]

Therefore, one great opportunity for heat pipe usage in the industry is to replace steam and water-cooling system. There are some advantages and disadvantages on this possibility:

Advantages:

- Reduced maintenance, labor, materials (chemicals and spare parts) costs.
- Reduced stock costs (spare parts and chemicals).
- Increased worker safety (reduced noise levels and hazard risks).
- Reduced waste water output.
- Reduced CO, CO_2, NO_X, SO_X emissions.
- Increased energy efficiency (less conversion processes).

Disadvantages:

- Increased energy dependence between different processes.
- Usually heat pipe is not considered in basic projects design.
- Equipments usually not available ready to buy (tailor made).
- Lack of experience and reliability on heat pipe equipments in industrial operations.

It is important to remember that scarcely a basic design will totally disregard steam use, because it has many other general applications in industry [4]:

- Stripping.
- Fractionation.
- Power generation.
- Mechanical drive.
- Quenching.
- Dilution.
- Vacuum draw.

Only steam for process heating is subject of substitution by heat pipe, provide there is a heat source on the process itself, with adequate characteristics namely available and required temperatures. Among these, considering some specific equipments and processes, there are many different temperatures range available in industry only regarding wasted heat as Table 4.

Table 4. Typical waste heat at diverse temperature range from various sources

Types of Device	Temperature, ^{o}C	
	Minimum	Maximum
Nickel refining furnace	1370	1650
Aluminum refining furnace	650	760
Zinc refining furnace	760	1100
Copper refining furnace	760	815
Steel heating furnaces	925	1050
Copper reverberatory furnace	900	1100
Open hearth furnace	650	700
Cement kiln (Dry process)	620	730
Glass melting furnace	1000	1550
Hydrogen plants	650	1000
Solid waste incinerators	650	1000
Process heaters	650	1450
Steam boiler exhausts	230	480
Gas turbine exhausts	370	540
Reciprocating engine exhausts	315	600
Heat treating furnaces	425	650
Drying and baking ovens	230	600
Catalytic crackers	425	650

Process steam condensate	55	88
Air compressors	27	50
Pumps	27	88
Internal combustion engines	66	120
Air conditioning/refrigeration condensers	32	43
Liquid still condensers	32	88
Drying, baking and curing ovens	93	230
Hot processed liquids	32	232
Hot processed solids	93	232

Adapted from reference [4]

There are many opportunities on heat recovery on the industry. Actually, the World still lacks an adequate technology for efficient use of excess energy, especially low grade waste heat. And all achievable savings from improvements are available to be obtained by appropriate heat pipe usage even altogether with steam system. Some examples adapted from [3–6]:

- Blowdown heat recovery can reduce a boiler’s fuel use by 2 to 5%.
- Every 25°C reduction in net stack temperature is estimated to save 1 to 2% of a boiler’s fuel use.
- Direct contact condensation heat recovery can save 8 to 20% of a boiler’s fuel use, but costs may be relatively high.
- For every 6°C that the entering feed water temperature is increased, the boiler’s fuel use is reduced by 1%.
- Reduce heat loss from condensate in a steam system can save over 1% of a facility’s total energy use.
- Recovering waste heat through a recuperator can reduce a kiln’s energy use by up to 30%; regenerators can save up to 50%.
- Recovering waste heat from furnaces, ovens, kilns, and other equipment can save 5% of a typical facility’s total energy use.
- Recovering waste heat can reduce a typical facility’s total energy use by about 5%.
- Preheating furnace combustion air with recovered waste heat can save up to 50% of the furnace’s energy use.
- Recovering flue gas waste heat to preheat boiler feedwater can reduce a boiler’s fuel use by up to 5%.
- Reusing heat in cascade within the diverse processes can reduce over 5% of a facility’s total energy use.

More options can be considered also by combination with other technologies like heat pumps and organic fluids Rankine cycles:

- Recycle heat condensation energy from top of distillation columns to bottom reboiler.
- Use energy outlet from gas turbines to cool air input and obtain higher efficiencies.
- Use low heat outlet from processes to produce small scale power to move pumps and compressors within the same plant.

Nowadays many industrial and commercial applications for heat pipe are already in course. Data from the Institute of Heat Pipe Technology, Nanjing University of Technology states that there were more than 370 different equipment by 2002, being used in industrial applications in China [7]. In that country also, even significant long distance closed loop thermosyphon are already in use to promote heat transfer between processes 50 meters away from each other. Other day-by-day larger size applications also begin to become more common like energy saving in air conditioning and dehumidification systems [8], industrial heat exchangers [9] and energy distribution uses [10].

Everything seems so shining bright! Isn’t something missing? Yes, comparative investment costs. Just supposing that investment costs on the main equipment of a steam system match in cost all needed investment on an equivalent heat pipe network to do the same task is a too big simplification. It must be taken in account that this move from micro to macro heat pipes will demand a big step for heat pipe technology. Changing from micra to meters will imply in bigger flow rates, distances and pressure drops. Nevertheless, some technical and non-technical barriers must be taken in equation as:

- Distance from heat source to heat sink related to entrainment and capillary limits inside heat pipe.
- Heat transfer rates related to sonic and boiling limits in heat pipe.
- Lack of technical and commercial reputation to be considered as a project option.
- Prejudice on investors and operators side to be considered actually applicable and reliable.

CONCLUSION

Enhancing heat recovery ought to be an important part of any company strategy for accomplishing lower costs, higher overall efficiency and environmental goals. Heat recovery is in fact a renewable and pollution-free energy. It can be used for heating, cooling, humidity control and power. This is where much room for heat pipe application in the industry lies.

This technology most be presented as more efficient, reliable and capable of using a variety of energy sources than other options. Including integration with low temperature waste heat, cogeneration and conventional heating and cooling systems, some points must be addressed as key advantages on using heat pipes:

- Attach to existing investments – it can be adapted to existing assets and improve their efficiency.
- Add shareholder value – it can be measured in terms of avoided operational and investment costs reduction obtained by its application, altogether with a sustainability image.
- Improve worker comfort and safety – since it reduces or avoids usage of more equipment, chemicals, fuels and demands less maintenance it can reduce working hazards.
- Environmental friendly - again less chemicals and fuels, it can reduce direct and indirect impacts to environment.
- Improved reliability and capacity utilization – it can reduce downtimes thru reduced maintenance frequency, improve productivity and be easily and quickly, scaled and designed to fit processes demands.

How to accomplish these aspects? Attracting and working together with the industry seems to be a decisive approach. Some other steps are suggested:

- Access and conduct technical audits of energy recovery opportunities, related costs and losses over the industry, specially potential sources, uses and costs of waste heat.
- Create partnership with industries that have bigger potential return over heat pipe advantages, to access data and investments opportunities for research and application.
- Create demonstration sites in various industrial applications to measure and quantify energy, comfort, productivity, health, safety and environmental benefits of heat pipe usage.
- Promote educational programs and communication about heat pipe technologies common applications for architects, engineers, the public, service technicians and investors in order to spread its potential use.

Nowadays, energy conservation and energy efficiency have gained a greater importance concerning environment and specially greenhouse gases emissions reduction. However, economics is still a major issue. Heat pipe can be an alternative weapon on this battle, providing all energy savings and same by products other technologies produce. But since it proves its availability, reliability and compared cost effectiveness, it can occupy a significant share of heat transfer and waste heat recovery in general industry.

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