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TECHNOLOGICAL RECOVERY POTENTIAL OF WASTE HEAT IN THE INDUSTRY OF THE BASQUE COUNTRY

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Abstract—The growing costs and the availability of fuels make it necessary to reduce energy consumption in industrial processes. The use of residual heat recovery technologies is an effective way of achieving an energy saving and, consequently, better efficiency in their use. In order to appropriately value the recovery potential of residual heat, it is necessary to know the detailed flow characteristics. It is also necessary to examine in depth the different heat recovery technologies, such as heat exchangers, Rankine and Brayton cycles, heat pumps, absorption cooling, expanders, burners and cogeneration systems, in order to be able to integrate the set (residual heat–recovery technology–useful flow). Using the available data of the Basque Country database and other databases of thermodynamical properties, the energy and exergy of waste heat for 10 industrial sectors of the Basque Country has been determined. They have been classified according to their type (gases, liquid effluents and sensible heat in solids), and also according to their thermal level (from under 353 K up to 1473 K). A methodology has been developed in order to assess the application potential of these eight heat recovery technologies. For this, software has been developed which takes into account the limitations of each technology, and makes a preliminary selection, indicating those recovery technologies that are potentially suitable for any industry. The results of this selection made for the industry of the Basque Country show that of the eight studied, heat exchangers and heat pumps are the technologies with the greatest potential for application. Copyright © 1996 Elsevier Science Ltd.

Keywords—heat recovery, industry, Basque region, technological assessment.

INTRODUCTION

El Ente Vasco de la Energía (E.V.E.) is the Basque office responsible for planning, coordination and control of energy activities in the Basque Country. In the last years it carried out several studies in order to know the technological and energetic situation of this autonomous community. At the present time, a group of databases for sectors are available, which are periodically modernized, and form the basis for the establishment of the specific energy policy [1].

Indeed, the characterization in the use of energy and/or raw materials in the diverse processes of the sectors has been improved and systematized. Nowadays it has reached such a degree of information, beyond its application in specific studies, that it could be used for the performance of contrast analysis for the determination of the technological level.

Any analysis, even a preliminary one, concerning the use of energy necessitates classification of the consumption not just in sectors, but essentially depending on the final uses, for types of energy and ranges of temperature. It is necessary, therefore, to make a breakdown of the energy consumptions of the greatest consumers sectors/subsectors according to types of energy, for different uses and levels of temperature.

Besides, once this breakdown has been made, it is also necessary to carry out an analysis of the efficiency in the use of the energy. This type of analysis should not be limited to relating the amounts of useful energy at the exit of the equipment with the amounts of energy supplied to them. It is necessary to carry out the analysis taking into account the quality of the energy, differentiating the energy flow not just for its content in energy, but also for its exergy.

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Table 1. Waste heat for the different industrial sectors of the Basque Country specified by temperature range

Thermal level	Energy (GJ)	Percentage
> 1473 K	10 673 000	21
1073–1473 K	5 907 000	11
673–1073 K	9 620 000	19
473–673 K	4 182 000	8
393–473 K	2 443 000	5
353–393 K	5 711 000	23
< 353 K	10 151 000	8
Others	2 502 000	5
Total	51 189 000	100

It is a complex task to determine efficiency in the use of energy, because it is necessary to consider a great number of factors which take part in each one of the processes and in the whole of their energy elementary operations. The purpose is to calculate the minimum theoretical consumptions as a base of reference in order to evaluate the degree of efficiency actually reached.

WASTE HEAT IN THE INDUSTRY OF THE BASQUE COUNTRY

In Table 1 the waste heat for the different industrial sectors of the Basque Country is defined in terms of temperature range. In this Table, the corresponding distributions in percentage are also included, referred to the total consumption of energy.

Division by type

The division by type of waste heat is presented in Table 2. As can be appreciated, gas stack exhausts, vapour (including steam) and gases (the most easily recovered types of waste heat), make up more than 50% of the total waste heat. Figure 1 presents the percentages of waste heat according to their thermal level and type.

Recovery technology considered

After the setting up of maintenance measures, the recovery of waste heat is the method of energy conservation that has been adopted in a great number of industries. Generally it does not require very large investments [2].

The main sources of waste heat are exhaust gases from combustion equipment, product streams and water streams. Exhaust gases are generally at relatively high temperatures, while water streams present moderate or low temperatures. Product flows are generally liquids at moderate or low temperatures, although they sometimes appear as solid products and also as high-pressure gases.

The energy of these three types of waste heat could be recovered and used basically in three different ways: power recovery (electricity), processes and building heating through the use of heat exchangers or heat pumps, and processes and building cooling or refrigeration by use of direct

Table 2. Waste heat for the different industrial sectors of the Basque Country specified by type

Types of residual heat	Energy (GJ)	Percentage
Gas streams	16 935 000	32
Solid product streams	13 856 000	27
Steams	8 181 000	16
Liquid streams	5 795 000	13
Others		
Gases	1 670 000	3.3
Radiation	1 423 000	2.8
Byproducts	1 310 000	2
Air	2 019 000	3.9
Total	51 189 000	100

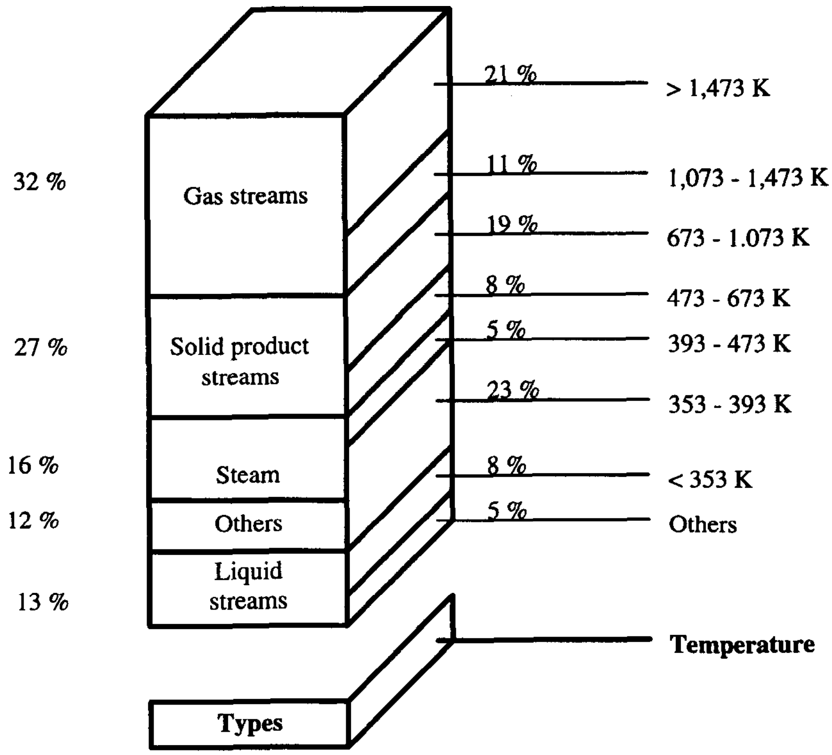

Fig. 1. Percentages of waste heat according to their thermal level and type.

expansion devices or even by thermally driven systems [3]. Table 3 summarizes the types of heat recovery technology considered in this research.

Determination of recovery technological potential

Before carrying out a relatively detailed study of the techno-economical viability of residual heat recovery for each one of the industrial plants that are stored in the database of the E.V.E., it is necessary to carry out a preliminary selection, in order to reject immediately those possible alternatives that do not present technical viability.

Table 3. Waste heat recovery systems

Application	Technology	Configuration
Power generation	Rankine cycle	Steam system
		Organic fluid system (ORC)
	Brayton cycle	Internal combustion
		External combustion
	Expanders	Axial flow turbine
		Condensing turbine
		Back pressure turbine
		Radial flow turbine
		Helical expander
	Stirling cycle	Intermediate heat transfer circuit
Heating	Heat exchangers	Tubulars
		Plates
	Heat pumps	Electrically driven
		Thermally driven
	Combustion	Fuel gas flow
		Post combustion
Cooling	Heat exchangers	Tubulars
		Plates
	Heat pumps	Thermally driven (Rankine cycle/inverse Rankine cycle)
	Absorption	Water/BrLi system
Electricity and heating	Cogeneration	Heat exchanger/open Rankine cycle
		Heat exchanger/closed Rankine cycle
Electricity and cooling	Cogeneration	Heat exchanger/expander

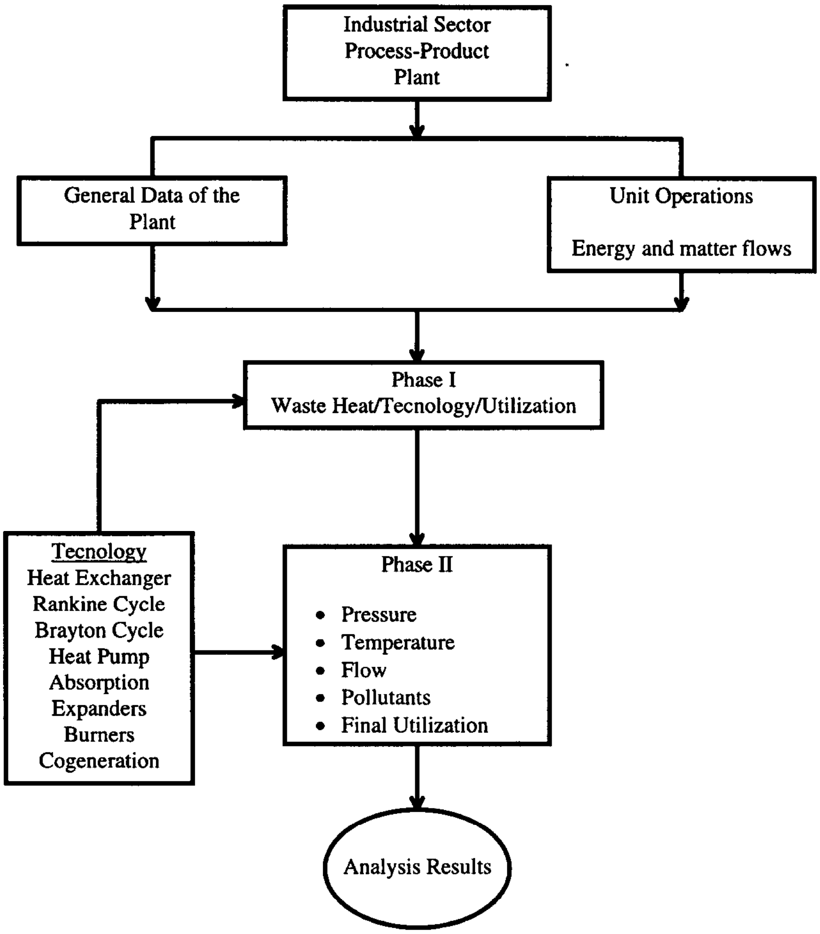

Fig. 2. Diagram of the prescreening.

Waste streams provide an energy source for the waste heat recovery technology that is considered and the end-use stream of this technology, that could be in the form of electricity, heat or cold, is the useful output provided by the technology.

In order that a certain technology passes this preliminary selection process, it is required, in the first place, that the individual waste-stream selected heat from the database corresponding to a certain industry must be compatible with the technology being screened [4]. In addition to this, it is necessary that the output provided by the mentioned technology must have an end-use application in the industrial process considered.

The prescreening is carried out in two phases. In the first place the industry in which all the unit operations, the several intermediate flows with their characteristics and all the raw materials and energy streams are defined is selected.

For each technology, a search of waste heat flows and end-use streams that would be suitable for this technology has been carried out. The second part of the selection process is to check whether or not the waste and end-use stream chosen are within the technological limits of the selected waste heat recovery technology [5]. Figure 2 shows a logical scheme on which the developed software is based.

RESULTS

The preliminary selection model has been applied to a total of 260 industrial companies, that total an annual energy consumption of over 126×10^6 GJ. We have considered waste heat divided into three types such as liquid outflows, gas and vapour waste streams.

Liquids

Table 4 presents the results that have been obtained by applying the selection model to the residual heat in the form of liquid. As can be shown, heat pumps are potentially able to recover a great part of that energy, achieving 60% recovery. It is necessary to take into account that in this phase of the study, any considerations of an economic nature have not been considered at all, only the technological viability.

Gas waste streams

Exhaust gases from combustion equipment present a high recovery potential due to the great amount of energy that they contain and to their high temperature levels.

The application of the prescreening model has revealed that heat exchangers dominate the energy recovery potential with a utilization level of 92%. This means that 92% of the total waste gas energy may be recovered, using a suitable heat exchanger. Rankine cycles are in second place in waste energy recovery, amounting to 10 200 GJ.

Vapour waste streams

Exhaust vapours, due their high energy content, present a potential of 100% for utilization by any of the above-mentioned technologies. The overall summary and ranking of technologies on utilization of all waste streams are also presented in Table 4.

CONCLUSIONS

The characteristics of eight residual heat recovery technologies have been examined, in order to predict their potential application in industry, having defined the range of application for each case. These technologies are: heat exchangers, Rankine and Brayton cycles, heat pumps, absorption cooling, expanders, burners and cogeneration systems.

In the same way, a methodology has been developed which allows us to assess the possibility of applying a waste heat recovery technology, from among those previously mentioned, in an industrial setting.

In short, it is a prescreening process, in which we analyse the technological compatibility among the characteristics of the waste flow, the end-use stream and the selected recovery technology. For this purpose, software able to consider the whole possible waste streams and technology combinations within a given industrial process has been developed.

Table 4. Final summary for all waste streams

Technology	Waste energy used		Recovery percentage
	Type	GJ	
Heat pumps	Gas	6 491 000	35
	Liquid	3 478 000	60
	Vapour	8 181 000	100
Heat exchangers	Gas	17 117 000	92
	Liquid	2 316 000	40
	Vapour	8 181 000	100
Rankine cycles	Gas	10 200 000	55
	Liquid	117 000	2
	Vapour	—	0
Cogeneration	Gas	9 300 000	50
	Liquid	117 000	2
	Vapour	—	0
Cooling absorption	Gas	5 580 000	30
	Liquid	288 000	5
	Vapour	326 000	4
Expanders	Gas	184 000	1
	Liquid	—	0
	Vapour	7 770 000	95
Burners	Gas	372 000	2
	Liquid	—	0
	Vapour	—	0
Brayton cycles	Gas	372 000	2
	Liquid	—	0
	Vapour	—	0

The application of this software to the Basque Country industrial database allows one to conclude that:

- For liquid streams, heat exchangers and heat pumps are the two technologies that present the greatest recovery potential.
- With regard to gas waste streams, heat exchangers offer the greatest heat recovery potential (92%), followed by Rankine cycles (55%) and cogeneration systems (50%). The expanders present a small recovery potential, that exactly reaches 1%, representing a total energy of 184 GJ.

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