Technology Surveillance of the Solar Refrigeration by Absorption/Adsorption

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***Abstract*--In order to establish networks of cooperation looking for not to duplicate research and even to make use of existing research in a remote form, it is necessary to identify and classify (around the world) the researchers and laboratories, that are researching in the topic of solar refrigeration by absorption/adsorption. The methodology consists in: i) the technology's classification, ii) technological trajectory identification, iii) a thematic bibliographic review, and iv) patent's analysis. In this way, with the previous determination of keywords, will be identified main authors and their respective institutions. With the same keywords, are determined the licensed patents (in certain span of time). In addition, the analysis of publications, patents, and commercial products give us an opportunity to establish comparisons between prototypes and tests (in several conditions). The larger results implicate the use of actor's network and the remote access to the data and tests, for a collaborative research, overcoming the lack of laboratory resource and accelerating the knowledge acquisition.**

I. INTRODUCTION

The refrigeration by ab/adsorption, that consumes thermal solar energy, enhances the possibilities of careful of the environment. In addition, it changes the traditional refrigerants for others that not damage the ozone layer. Furthermore, facilities the development and application of adsorbent materials, as zeolites and silica gel among others.

Desideri et al [1] have carried out a technical and economic analysis of solar air-conditioning applications by ab/adsorption. While that [2] conducted a comparative analysis of these systems with the refrigeration systems by ejectors.

The investigations in this theme at Hispano-American level, reflected in patents and/or publications, are relatively low, in spite of the considerable possibilities of application. The objective of the research is to find research networks or groups, as well as the technological trajectory that was followed in this theme, in order to contribute to design the strategy of investigation.

The subjacent question at the present investigation is, how to boost investigation and applications in the theme of solar refrigeration by ab/adsorption?

The hypothesis is, H1: If is performed a technological surveillance in the topic: solar refrigeration by ab/adsorption, will be possible to count with elements to take decisions for a better technological positioning.

Also is possible, as advocated by [3], i) utilizing the technological surveillance to find investigations performed aiming to utilize its data for new studies, without the necessity to resort the evidences of laboratory, in other words to generate new knowledge, and ii) to make inferences through the intersection between related fields.

II. TECHNOLOGICAL SURVEILLANCE

The technological surveillance allows mapping the actual state of one determined technology, by means of identification of researchers/inventors linked to the theme, through the identification of their publications and/or patents. The researchers/inventors linked to laboratories, organizations, groups of researchers, universities, enterprises, among others are the actors to produce new technology.

The technological surveillance has been included in the beginning of the process of research, development and innovation, in the existent technological normative [4]. This implicates that, the technological surveillance is the starting point to the development of the processes of innovation.

Establishing analogy between technological surveillance and the technique of Observation-Orientation-Decision-Action (OODA) proposed by [5], would implying that the technological surveillance corresponds the moments of observation and orientation of the OODA, while the competitive intelligence would be analogous to the decision and action.

The observation will implicate the determination of the theme to surveillance, the technological trajectory itself as well as the behavior of the technological system.

Dosi [6] pointed out, that *"the technological trajectory is the direction of advance inside a technological paradigm"*, by the causal relationship with the past, that has implicated evolution of the technological systems. According Altshuller and its followers [7], such evolution is governed by ten laws: the integration of parts, transmission of energy, harmonization of phases, increasing ideality, lagged development relative of the systems, transition to a technological super-system, transition from the macro system to micro system, dynamic increment, more interaction between substance and field, and psychologic inertia.

Thus, according to those authors, the technological systems evolve 10 laws. However the development of the technological systems occurs with different pace, so some systems have more quick development than others, this imply that some inputs or parts could not yet be available, nor developed still, because belong to a more lagged system. Besides, the evolution of the technological systems could be the summation of the "S" curves.

Escorsa & de la Puente [8], that have coined the concept of dual technology tree, hold that:

> *"Technological change is a leap from one branch to another. If the branches are far apart must go back much in the branch to connecting, because has produced a technological breakthrough. The distance between branches can used to measure the relationship*

between two technologies. This distance measures the degree of vulnerability of the technology of a company facing the innovation in the other branch".

The orientation step corresponds with the search of publications and/or patents about the theme delimited in the observation stage.

At the end of this stage is possible, with the same variables, develop technological forecast studies and/or technological foresight studies. In particular is possible to forecast the disruptive innovation according the evolution of the technological system [9].

Porter & Newman [3], for its part profess that could performed investigations with data, tests and results, obtained in distant laboratories, and that already had had utilized to other publications. These authors at the letter said: *"... that one can discover a new finding via pattern recognition - a finding that is not itself present in those data",* with that sustain its *"discovery of structured knowledge"*.

These authors also support that is possible to perform discoveries based in the literature, by the intersection of different themes, through keywords, looking for new knowledge.

III. REFRIGERATION SYSTEMS BY AB/ADSORPTION WITH SOLAR ENERGY

According reference [2] the thermally driven cooling technologies would be classified into two categories: ab / adsorption technology (open or closed systems), and thermo-mechanical (ejector system) technology.

Both the absorption as the adsorption are physical-chemical techniques of separation. In the first case, the steam is absorbed by liquid, while in the, second case the steam is adsorbed by a solid, after that, in both cases the refrigerant is liberated. The intra-molecular forces are greater in the absorption than in the adsorption, at this point, the authors argued that *"the adsorption refrigeration typically needs lower heat source temperatures than the absorption refrigeration"* [2].

Both of them, the refrigeration by absorption and the refrigeration by adsorption, are based in similar principles, so in the first case the liquid incorporates the refrigerant steam, whereas in the second case a solid incorporates the refrigerant steam.

A. Refrigeration systems by absorption

They are based on the absorption principle by which a fluid or gas in vapor state is absorbed by a liquid, forming a binary solution. Then heat is supplied to this binary solution to release the absorbent. When the released refrigerant passes through the condenser, dissipates heat to the surrounding medium, and after passing through a valve, reaches the evaporator where it receives heat from the medium to refrigerate.

B. Refrigeration systems by adsorption

Based in the physical-chemical principle of the adsorption by which an adsorbent material adsorbs spontaneously the fluid, which as soon receive the heat it is released. The refrigerant fluid after released flows towards the condenser where dissipates its heat, after passing the throttling valve reaches the evaporator where catches heat of the mean to be refrigerated.

C. Use of the solar energy in refrigeration systems by ab/adsorption

Caciula et al [10] manifest that "there is few experience and little knowledge in the planning and design of solar cooling systems and there is no standard and complete guide available for designing the entire system".

As has pointed out, both systems of refrigeration, by absorption and by adsorption, require heat as a source of energy. This heat can come from exhaust gases, combustion of natural gas, the solar energy, among other sources.

These two technologies (absorption and adsorption) constitute two branches of the dual technology tree. On the other, both of them, together with the refrigeration by injection of steam, are appropriate to make the solar refrigeration.

IV. METHODOLOGY

The methodology applied was:

- Apply techniques of technology surveillance. The patents have identified by the use of software Matheo Patent. It was considered applicant institutions with two or more patents.
- The publications have been mapped since those registered in the dataBase SCOPUS of Elsevier, which yields points for the ranking of SIR.
- In accordance with the recommended by [3] have been identified and analyzed 10 prototypes of solar absorption refrigeration, and 10 prototypes of solar adsorption refrigeration.

V. RESULTS

So much the systems of refrigeration by absorption as by adsorption utilizing solar energy have had technological development, as identified by the number of patents and publications presented. One system that converges would be of solar collectors to capture thermal solar energy and feed the apparatus of refrigeration by ab/adsorption. Other system is of polymeric hydrogels materials, among others, utilized as adsorbents.

A. Solar refrigeration with both techniques of separation (absorption and adsorption)

According to keywords reported and since the year 2000, in the database SCOPUS, it was found the following papers:

TABLE 1 SOLAR REFRIGERATION BY AB/ADSORPTION

Keywords:	No. of papers
"refrigeration" and "absorption" and "adsorption" and "solar energy"	27
"air conditioning" and "absorption" and "adsorption" and "solar energy"	18
"refrigeration" and "air conditioning" and "absorption" and "adsorption" and "solar energy"	08

Keywords:	Authors with more published papers	
	Authors	No.
"refrigeration" and "absorption" and "adsorption" and "solar energy"	Wang, R.Z.	04
	Li, M.	02
	Fong, K.F.	02
	Lee, C.K.	02
	Zhang, X.J.	02
"air conditioning" and "absorption" and "adsorption" and "solar energy"	Fong, K.F.	02
	Lee, C.K.	02
"refrigeration" and "air conditioning" and "absorption" and "adsorption" and "solar energy"	Fong, K.F.	02
	Lee, C.K.	02

Source: Elaboration by authors from the SCOPUS access in 25/01/2016

B. Refrigeration by absorption with solar energy

Following the issue and taking only the branch of the refrigeration by absorption in the dual technological tree, the results of the search of papers led to the data, as in the Table 2.

Among 33 publications linked to prototypes of refrigeration by absorption, were selected 10 that according to abstracts have implicated the construction and testing of the prototype.

TABLE 2 REFRIGERATION BY ABSORPTION WITH SOLAR ENERGY

Keywords:	No. of papers
"refrigeration" and "absorption" and "solar energy"	175
"air conditioning" and "absorption" and "solar energy"	129

Keywords:	Authors with more publications	
	Authors	No.
"refrigeration" and "absorption" and "solar energy"	Wang, R.Z.	07
	El-Halwagi, M.M.	06
	Goswami, D.Y.	06
	Ponce-Ortega, J.M.	06
	Lee, C.K.	05
	Fong, K.F.	05
	Serna-Gonzalez, M.	05
	Sozen, A.	05
"air conditioning" and "absorption" and "solar energy"	Fong, K.F.	06
	Lee, C.K.	06
	Li, Z.F	05
	Sumathy, K.	05
	Chow, T.T.	04
	Lin, Z.	04
	Rosiek, S.	04
"refrigeration" and "air conditioning" and "absorption" and "solar energy"	Fong, K.F.	04
	Lee, C.K.	04

Institutions with more papers in refrigeration by absorption:	
University:	No
Shanghai Jiaotong University	15
Texas A and M University	08
Xi'an Jiaotong University	06
Huazhong University of Science and Technology	06
Universidad Michoacana de San Nicolas de Hidalgo	06

Prototypes built and tested on refrigeration by absorption	
Keywords	Number of publications
"refrigeration" and "absorption" and "prototype"	33
"refrigeration" and "absorption" and "prototype" and "experimental"	22

Source: Elaboration by authors from the SCOPUS

TABLE 3 PUBLICATIONS ABOUT PROTOTYPES OF REFRIGERATION BY ABSORPTION

Publication	Absorbing and refreshing	Parameters considered
Experimental evaluation of a variable effect LiBr water absorption chiller designed for high-efficient solar cooling system [11]	LiBr/water	Cooling capacity: 50 kW COP: 0.69 to 1.08 Generation temperature: 95 ºC to 120 ºC
Solar-powder single and double effect directly air cooled LiBr-H2O absorption prototype built as a single unit [12]	Lithium bromide/water	48 m^2 field of flat-plate solar collectors, single effect (4.5 kW), double effect (7 kW),
Pre-industrial development and experimental characterization of a new water – cooled ammonia / lithium nitrate absorption chiller [13]	Ammonia/lithium nitrate	Cooling capacity = 12.9 kW
Experimental studies on an air – cooled two stage $NH_3 – H_2O$ solar absorption air – conditioning prototype [14]	Ammonia/water	Cooling capacity = 2 kW
A novel experimental investigation of a solar cooling system in Madrid [15]	$LiBr/H_2O$	49.9 m^2 array of flat-plate collectors COP = 0.6; 0.42; 0.34 Peak insolation = 969 W/m^2
Experimental and numerical analysis of an air-cooled double-lift NH_3 - H_2O absorption refrigeration system [16]	NH_3 - H_2O	Chiller water inlet: 12 ºC Chiller water outlet: 7 ºC Hot water driving: 80 ºC to 90 ºC Cooling capacity = 2.5 kW COP = 0.3
Solar thermally driven cooling systems [17]	H_2O/LiBr	Refrigeration capacity COP Chilled water temperature Evaporation temperature in the evaporator
Application of solar cooling technology for rural areas in Botswana [18]	Ammonia/water	Prototype is under construction
Development and testing of a prototype of low-power water-ammonia absorption equipment for solar energy applications [19]	H_2O/LiBr	2 kW refrigeration equipment
Residential solar air conditioning: Energy and exergy analyses of an ammonia-water absorption cooling system [20]	Ammonia/water	10 kW air cooled ammonia-water absorption chiller driven by solar thermal energy

Source: Elaboration by authors from the SCOPUS

C. Refrigeration by adsorption with solar energy

In a similar way as performed for the branch of refrigeration by absorption, was made for the branch of refrigeration by adsorption.

From 28 papers linked to prototypes of refrigeration by adsorption, were selected 10 that according to abstracts had implicated the construction and testing of the prototype.

TABLE 4 REFRIGERATION BY ADSORPTION WITH SOLAR ENERGY

Keywords:	**No. of publications**	
"refrigeration" and "adsorption" and "solar energy"	119	
"air conditioning" and "adsorption" and "solar energy"	57	
Keywords:	**Authors with more publications**	
	Authors	**No.**
"refrigeration" and "adsorption" and "solar energy"	Wang, R.Z.	46
	Li, M.	14
	Dai, Y.J.	09
	Wu, J.Y.	09
	Xu, Y.X.	07
	Luo, H.L.	05
	Mimet, A.	05
	Zhang, M.	05
"air conditioning" and "adsorption" and "solar energy"	Fong, K.F.	02
	Lee, C.K.	02
"refrigeration" and "air conditioning" and "adsorption" and "solar energy"	Fong, K.F.	02
	Lee, C.K.	02
Institutions with more papers in refrigeration by adsorption:		
University:		**No**
Shanghai Jiaotong University		57
Yunnan Normal University		11
Shanghai Ocena University		05
Alfaisal University		05
Universiti Kebangsaan Malaysiade		04
Prototypes of refrigeration by adsorption		
Palabras-clave		Number of papers
"refrigeration" and "adsorption" and "prototype"		43
"refrigeration" and "adsorption" and "prototype" and "experimental"		28

Source: Elaboration by authors from SCOPUS by access 18/12/2015

TABLE 5 PUBLICATIONS THAT REPORTS PROTOTYPES OF REFRIGERATION BY ADSORPTION

Publication	**Adsorbent and refrigerant**	**Parameters considered**
Influence of the design parameters on the overall performance of a solar adsorption refrigerator [21]	Silica-gel and water	mass of silica-gel, number of metallic fins in the silica-gel bed, the orientation of the solar collector (azimuth angle), improvement of the collector's cooling during the night, thermal contact resistance between silica-gel and the collector plate, condenser surface area, evaporation surface area, radiant properties of the collector plate, thermal insulation of the refrigerated cabinet.
Experimental investigation of an adsorption refrigeration prototype with the working pair of composite adsorbent-ammonia [22]	calcium chloride/activated charcoal and ammonia	mass recovery time, cycle time, heating temperature, evaporating temperature, cooling water temperature
Solar adsorption refrigeration system using different mass of adsorbents [23]	activated charcoal and methanol	different mass ratios of activated charcoal-methanol from 0.250 to 2.50
Experimental analysis of an adsorption refrigerator with mass and heat-pipe heat recovery process [24]	$CaCl_2$ - activated carbon and ammonia	*"Specific cooling power (SCP) and coefficient of performance (COP) were calculated with experimental data"*
Optimization of solar adsorption refrigeration system using experimental and statistical techniques [25]	Activated charcoal and methanol	COP, Cooling production
Study of a novel silica gel-water adsorption chiller. Part II. Experimental study [26]	Silica-gel and water	Refrigeration capacity, COP
Experimental results and analysis for adsorption ice-making system with consolidated adsorbent [27]	Activated charcoal and methanol	COP, Specific cooling power,
A combined cycle of heating and adsorption refrigeration: Theory and experiment [28]	Charcoal and methanol	COP system, COP cycle, Ice making
Adsorption refrigeration in Shanghai Jiao Tong University [29]	Activated charcoal	Ice making
Two-stage non regenerative silica gel water adsorption refrigeration cycle [30]	Silica - gel and water	Cooling capacity, COP

Source: Elaboration by authors from SCOPUS

D. Patents

1) Refrigeration by absorption with solar energy

The patents had been identified - using the software Matheo Patent - through the introduction of the keywords: "solar energy" and "absorption refrigeration" since year 2004 onward.

It was identified 43 patents. Being the countries of major number of inventors: China with 21 patents, Australia with 03 patents, Great Britain with 01, and USA with 01. The prevalence of China by patenting in this technology is evident from this study. The institutions that presents with 02 or more patents in this theme are:

TABLE 6 NUMBER OF PATENTS BY INSTITUTION

Institution	No. patents
University of South China of Technology	03
Chen Shichao	03
University of Nanjin of Aeronautics	02
University of Beijing of Technology	02
Farquhar Roger A.	02

Source: Elaboration by authors from CIP

Where again can notice the presence of 03 Chinese universities among the best ranked. It is important to notice that in this list there is no Hispano-American countries nor universities of this region. Table 7 presents the international classification of patents - CIP - as well as the number of patents according to each class:

TABLE 7 NUMBER OF PATENTS BY CLASS

IP Class	No. patents
F25B	39
F24J	18
F24F	06
H01L4	04

Source: Elaboration by authors from CIP

Being the predominance in the classes F25B, F24J, F24F.

2) Refrigeration by adsorption with solar energy

Due to the contingency of not be able to use the software Matheo Patent, we resort the European Patent Office - EPO trough the introduction of the keywords: "solar energy" and "adsorption refrigeration" since year 2004 onward.

Were identified eleven patents: ten belonging to China and one of USA.

VI. ANALYSIS OF RESULTS

In the Tables 1, 2 and 3 can observe that the number of papers published on the theme (27), two techniques of separation (absorption and adsorption) increase substantially when analyzed separately, thus, 175 for absorption and 119 for adsorption. Regarding to the prototypes built and tested were identified 22 by absorption and 28 by adsorption, as in table 9.

TABLE 8 PATENTS BY INSTITUTION

Patent	**Institution**	**IP Class**
Solar-driven jetting-dual-adsorption-bed combined refrigeration system	University of Chongqing	F25B25/00
Heat exchanger operation auxiliary system and heat exchanger system using system	University of Henan Science & Technology	F25B17/08
Indirect evaporation coupling solar cold and hot combined supplying system for rural family	University of Guangdong Ocean	F25B27/00
Cool-storage type solar energy adsorption refrigeration house	Wuhan Yuhe Dingyu Refrigeration Technology Co Ltd	F25D13/00
Finned tube type solar adsorption refrigeration system	Yunnan Normal University	F25B27/00
Adsorption type low temperature heat resource power generation and refrigeration device	University of Shanghai Jiaotong	C09K5/00
Solar complex energy device for refrigerated storage and desiccation of agricultural products	University of Kunming Science & Technology	A23B9/00
Water generation from air utilizing solar energy and adsorption refrigeration unit	Adnan Ayman Al-Maaitah,	F25B27/00
Mini size distributed type solar energy driven combining system for supplying cool, hot energy and electricity	University of Shanghai Jiaotong	F24D17/00
Solar energy adsorption type refrigerating fresh-keeping warehouse	University of Tianjin Commerce	F25B27/00
Apparatus for water production from air by employing solar-powered intermittent absorption refrigeration	University of Tianjin Commerce	E03B3/28

Source: Elaboration by authors from EPO

TABLE 9 PUBLICATIONS IN "ABSORPTION" AND "ADSORPTION"

	"absorption" and adsorption"	"absorption"	"adsorption"
"refrigeration" and "solar"	27	175	119
"prototype" and "experimental"		22	28

Source: Elaboration by authors

Regarding to publications, the first place is occupied solely by only one author who boasts 07 and 46 articles, respectively, among eight authors with major publications so much in the solar refrigeration by absorption as by adsorption. This fact reinforces the proximity between the two branches of the same dual technological tree, the branch of the refrigeration by absorption and the branch of the refrigeration by adsorption.

In the prototypes selected, that are referred so much refrigeration by absorption as the refrigeration by adsorption, it found that:

TABLE 10 PAIR REFRIGERANT/ABSORBING AND PAIR REFRIGERANT ADSORBING IN THE PROTOTYPES IDENTIFIED

	Refrigeration by absorption		Refrigeration by adsorption	
Pair refrigerant/ absorbing	H_2O/LiBr	05		
	NH_3/H_2O	04		
	Ammonia/lithium nitrate	01		
Pair Refrigerant/ adsorbing			H_2O/Silica gel	03
			Methanol/ activated charcoal	05
			Calcium chloride /activated charcoal and ammonia	02

Source: Elaboration by authors

It can finding in the prototypes of refrigeration by absorption the predominance of the pair H2O/LiBr for applications in low temperatures as for air conditioning. While in the prototypes of refrigeration by adsorption, the preference is the pair methanol/activated charcoal, followed closely by the applications with the pair: water and silica gel.

There is not correlation between the universities with more publications and those with more patents, in the solar absorption refrigeration theme. However, in the theme of solar adsorption refrigeration, Shanghai Jiatong University and Yunnan Normal University, both of them have publications and patents.

VII CONCLUSIONS

The two branches of the dual technological tree of the solar refrigeration, that means, the refrigeration by absorption and the adsorption refrigeration should be researched with more emphasis in Peru. It should be privileged the pair water / lithium bromide, water / silica gel, and methanol / activated charcoal, by its tendency in the world research and because some investigations have been performed locally even if sporadically in these themes.

From the prototypes and studies identified, about the solar refrigeration, so much by absorption as adsorption, it has opened the possibility to perform the comparative study between prototypes and results of tests, to yield new knowledge.

The identification of the universities with more publications and patents in the topic of solar refrigeration by adsorption, like Shanghai Jiatong University and Yunnan Normal University, gives the opportunity for establishing formal and informal collaboration networking with them. This imply that in adsorption refrigeration there are more possibilities for new researches, highlighting the corresponding relation between knowledge and creativity.

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