

VACUUM CHAMBER SOLAR COLLECTOR DEVELOPMENT USING TRIZ METHODOLOGY

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ABSTRACT

The purpose of this paper is to describe the development process of a new solar collector concept that allows achieving the performance of vacuum tube solar collectors but at the price of flat plate solar collectors. It is shown how the TRIZ methodology helped to solve technical and physical contradictions during the development process.

Keywords: Solar energy, Solar collector, TRIZ

1. INTRODUCTION

One of the industries that have been reporting mayor growth rates around the world is the alternative energies' industry. This is due to a lot of factors, but mainly because of the exponential growth of the population around the world. Every year mankind requires more energy and since we obtain most of it from fossil fuels the damage we do to our planet is becoming bigger. Since this kind of energy sources are not renewable every year they are becoming more expensive and the chances that the prices go down or stabilize are slim to none. One of the mainstream alternative energies is solar energy, this because its advantages are far better that the disadvantages. Solar energy is divided in to two mayor branches Photovoltaic (PV), and Solar Thermal (ST). Solar Thermal is gaining in importance since as of today it is the one that allow us the shortest payback period, and it is developing at a very impressive speed. Due to this fact innovation is a must for any company that wants to succeed in this industry. The use of TRIZ to develop the Vacuum Chamber Solar Collector (VCSC) will be described in this paper

2. BACKGROUND

The current project is derived from a project done for the Centro de Energía Solar (Solar Energy Center) of the Instituto Tecnológico y de Estudios Superiores de Monterrey, commissioned by the Prof. Dr. Jose Angel Manrique (†), who was the chairman of said center. The project consisted in the design of a low cost, high efficiency solar collector capable of supplying the heat required by a 3 ton absorption air conditioner using 10m^2 or less. Said absorption air conditioner was developed and patented by Prof. Manrique in 1995 [1]

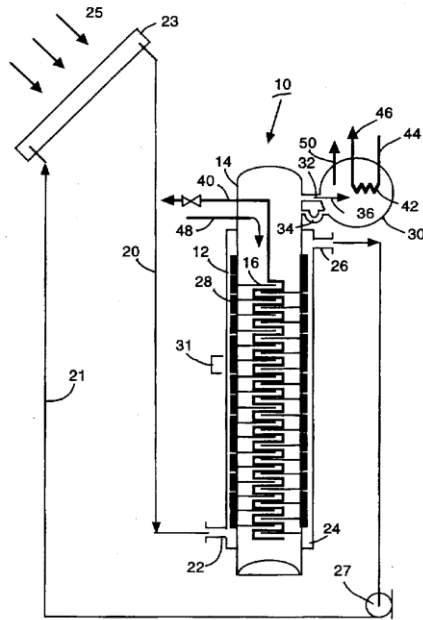


Fig. 1 Esquema de la máquina de enfriamiento por absorción del Dr. J.A. Manrique

Actually the ITESM 's Solar Energy Center has two absorption air conditioners (3 & 5 tonnes). As it is stated in the aforementioned patent this kind of air conditioner uses heat as its main energy source instead of electricity. The technology had already been proven with satisfactory outcome, but the heat source used (vacuum tube solar collectors [2]) was expensive (1000 EUR /m²; it required about 10m²). A simple solution to obtain cost reduction would be to use flat plate solar collectors [2, 3] since they are cheaper, but using this kind of collector are not able reach the necessary temperature of 150 °C.

3. FUNDAMENTALS

Basically in this application a solar collector needs to achieve high operation temperature and minimum losses due to ambient temperature. This requires good insulation, but this insulation should not block the solar energy.

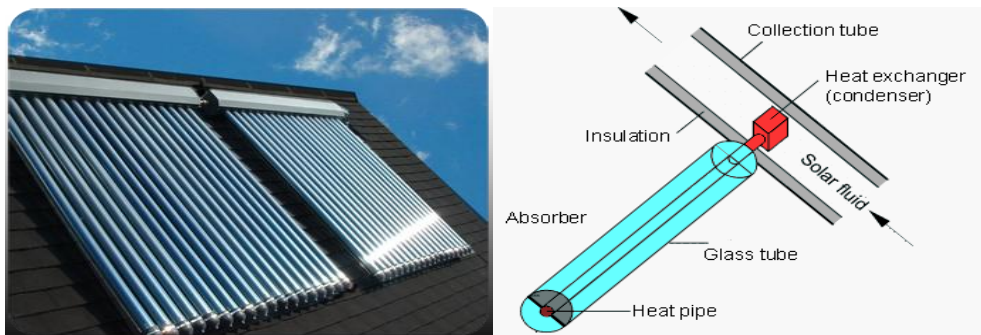


Fig. 2 Colector solar de tubos al vacío con esquema de funcionamiento

What is commonly done to achieve the desired effect is using vacuum as insulation against convection losses, so convection losses are practically eliminated [4, 5].



Fig 3. Flat plate solar collectors at “Casa Solar” from Tecnológico de Monterrey

The basic array to construct conventional vacuum tube solar collectors consists of inserting heat pipes inside borosilicate tubes. A hermetic joint is created between the glass and the metallic heat pipe so it does not leak vacuum. The heat pipe transfers the heat to a working fluid.

The major problem with this kind of collector is that due to the different expansion coefficients between glass and metal and to the high temperature changes in the collector plate the vacuum seal fails and the assembly loses the vacuum insulation.

3.1. USING TRIZ FOR SOLVING TECHNICAL AND PHYSICAL CONTRADICTIONS.

As with any new product that implies some kind of innovation the development of the vacuum chamber solar collector (VCSC) required the use of tools and methodologies to guarantee that at the end it would end up being a real innovation. Among the most important tools used for the development of the VCSC is TRIZ [6, 7].

As basic requirement of the project it was mandatory to create a solar collector capable of having an operation temperature of around 150°C by maintaining high efficiency and good performance even in bad weather conditions but at a cost approximately the same of the cheaper flat plate solar collectors.

To achieve these goals the team departed from a FPSC and analyzed different methods to isolate the collector plate without obstructing the solar radiation.

After several mathematical analyses the team realized that only by using vacuum as insulation it was possible to achieve the stated goals. Therefore the first question was how to apply vacuum to a flat plate solar collector and sustain the vacuum over large time periods. This was actually the “easy” part of the question as it is possible to install a vacuum pump driven by a photovoltaic cell beside the solar collector as shown in figure 4.

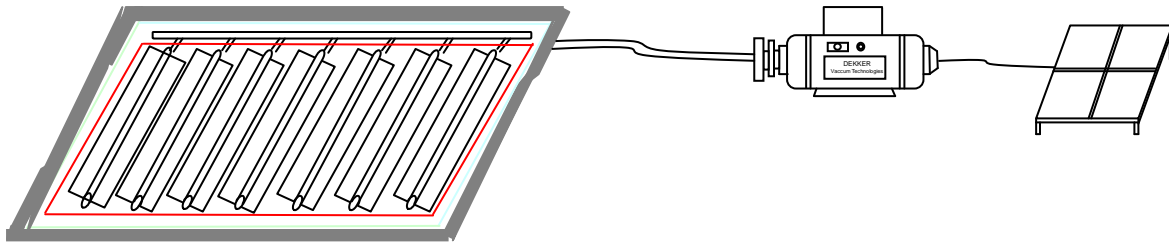


Fig 4, Flat plate vacuum solar collector with vacuum pump and PV cell

However, applying vacuum to a conventional flat plate solar collector leads to more difficult problems as the vacuum acts on the large surfaces creating large forces and deformations and consequently cracks and leakage losses. These problems required new solutions that were analyzed using the morphological matrix shown in figure 5.

Receive solar energy		Increase effective area	Add concentrating devices	Add tracking devices
Transmit solar energy		improve glass composition	Reduce glass thickness	Change critical joints
Preserve solar energy	Inner air convection	Create vacuum	Include honeycombs	Use better tray materials
	Outside air exchange	Seal the box		
Absorb more energy		Change collector plate material	Change collector plate form	Increase contact area
Heat transfer between plate and fluid		Change collector plate material	Control internal flow	Increase contact area

Fig. 5 Morphological matrix to develop new design of Vacuum solar collector

After organizing the whole design process with the morphological matrix, TRIZ was used to develop a new design that would allow to sustain vacuum avoiding the problems described.

The main identified technical contradictions were:

- A. To sustain efficiency of the collector it is necessary to avoid vacuum loses. If vacuum loses are generated by any cause a vacuum pump would be necessary to sustain an acceptable vacuum, the problem is that the pump would require electricity that increases the costs.
- What needs to be improved? Maintain high vacuum levels inside the collector
 - What deteriorates due to the conflict? Increased vacuum pump usage
 - Generalized Altshuller parameters: loss of substance vs. energy used by stationary object.
 - TRIZ principles used to solve the conflict: Replace mechanical pattern, porous materials (avoid)
- B. While heating a fluid using solar collectors the larger the absorber area the more energy is received. The problem with this is that to have a larger absorber plate area using conventional flat plat solar collectors a larger box is needed and as a result the thickness of the upper glass cover and of the box walls have to be increased to support the high vacuum level required.
- What needs to be improved? Increase absorber plate surface
 - What deteriorates due to the conflict? Bigger vacuum pump, thicker upper glass cover and thicker box walls.
 - General parameters: stationary object area vs. energy used by stationary object & weight of stationary objects.
 - TRIZ principles used to solve the conflict: Since there is not a proposed solution in the matrix, the team decided to use parameter 22 (energy waste) instead of 20 (energy used by a stationary object).
 - This turned principles 17, 7 and 30:
 - 17. Move to a new dimension
 - a. To solve a problem of an object that moves only in one direction it is possible to move it in a plane (2 dimension) and if that is not enough it can be moved in a volume (3 dimension)
 - 7. Nesting
 - a. Enclose an object inside another
 - b. One object goes trough another.
 - 30. Thin film or flexible membrane
 - a. Replace actual construction with flexible membrane and thin film
 - b. Isolate an object using flexible membranes or thin film
 - For the second technical contradiction, parameters 6. Area of stationary object and 2. Weight of stationary object: This turned principles 30, 2, 14, and 18:
 - 2. Principle of removal
 - Remove either the disturbing part or the necessary part from the object
 - 14. Principle of spheroidality:

- a. Switch from linear to curvilinear paths, from flat to spherical surfaces, etc.
- b. Make use of rollers, ball bearings, spirals.
- c. Switch from direct to rotating motion. Use centrifugal force.

It was concluded that the use of concepts 17, 7 and 14 were the ones that were going to provide the best options for a good solution and that concept 30 would be better suited for future developments.

C. One of the main variables that affect the efficiency of the collector is the thickness of the cover plate: It has to be thick so it can withstand the vacuum but it has to be thin in order to increase the transmittance. This is a physical contradiction. The team decided to analyze it also based on its conflicting parameters as technical contradiction:

- What needs to be improved? Increase cover plate thickness
- What deteriorates due to the conflict? Transmittance is reduced
- General Altshuller parameters: pressure difference vs. energy loss.
- TRIZ principles used to solve the conflict:

2. Extraction

- a. Remove one part or more

36. Phase transition

- a. Implement and use phase transition effect

25. Self-service

- a. Make that an object self-service and only execute supplementary repairs

After analysis and interpretation of principles 17, 7 the resulting solution was to accommodate vertical supports under the cover so the forces would be distributed. After reviewing the patent database it was found that a similar solution already existed (US 4,881,521).

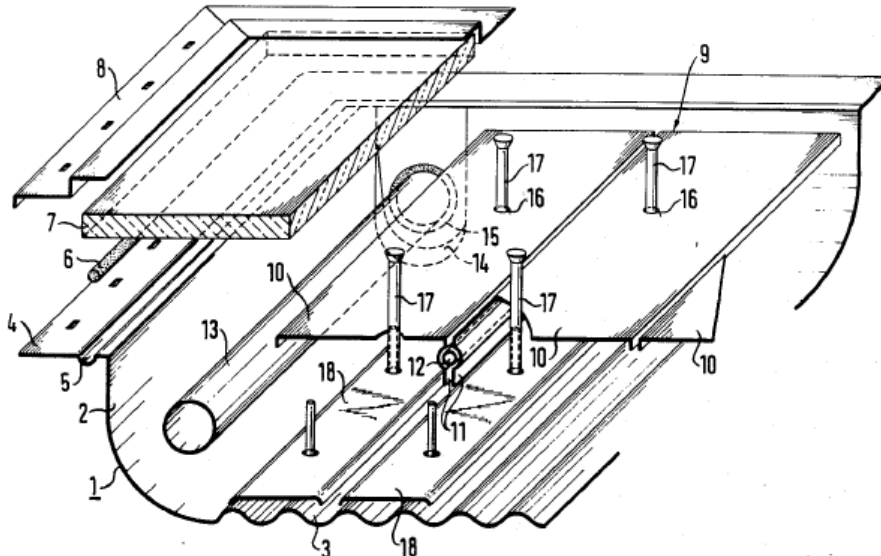


Fig. 6: US Patent 4,881,521 Vacuum Collector

The next figure shows the first new concept developed, and instead of multiple supports it uses walls to support the cover plate.

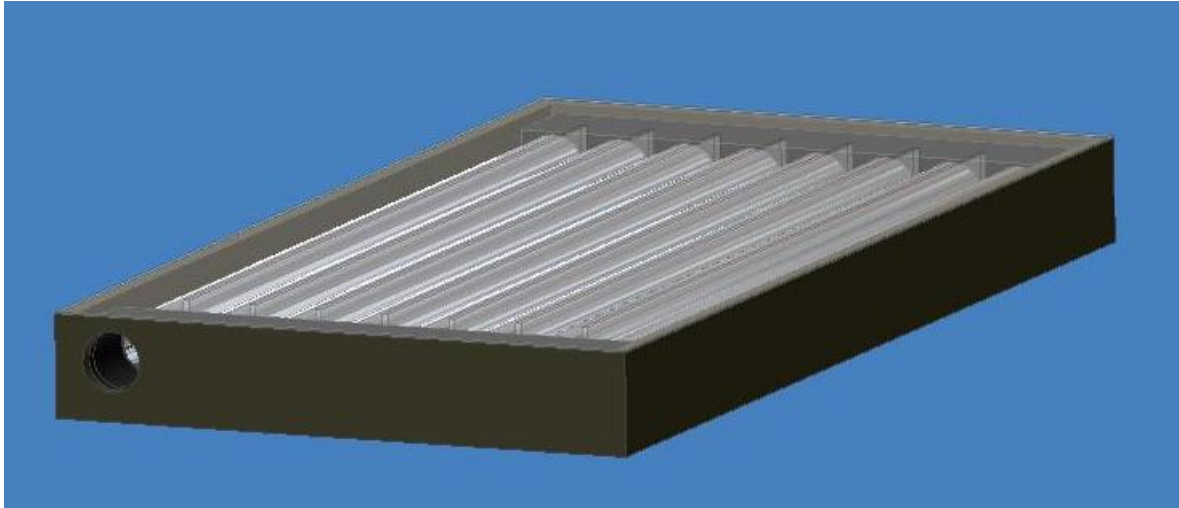


Fig 7. Flat plate vacuum collector using walls

After reviewing the design and a cost benefit analysis it was determined that using tubes (Principle 14 Spheroidality) was a better option since they would distribute the forces evenly and also eliminate the need of a box. So the collector was composed of the tubes and two headers, as it is shown in figure 8.

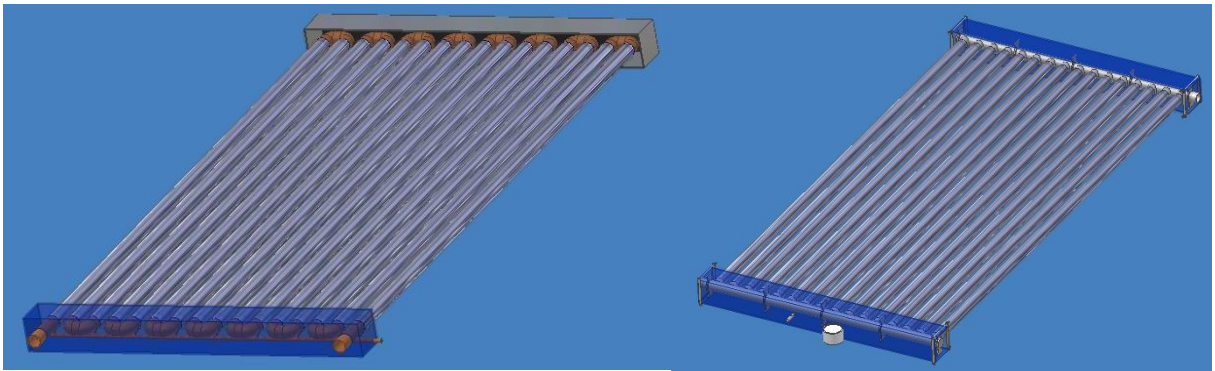


Fig. 8: Two variants of vacuum chamber solar collector (VCSC)

Using tubes allow for an evenly distribution of the forces generated by the vacuum.. Due to the concept achieved there are no longer glass-metal joints so the enclosure (chamber) was better sealed and this consequently eliminated the need of the vacuum pump. Also materials were used that allowed better optic and thermal performance thus reducing the size of the collector for the same amount of energy. Figure 10 shows segmented headers.

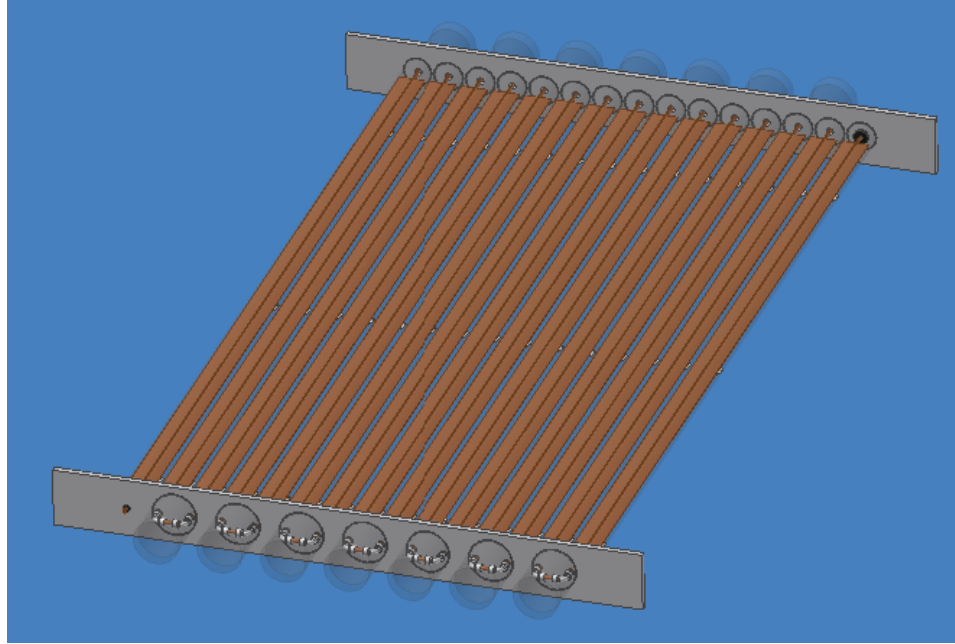


Fig 10: VCSC using segmented headers



Fig 11: First Prototype of the VCSC with segmented headers

4. CONCLUSIONS

It is considered that the success of the project was mainly because of the use of TRIZ. This allowed breaking paradigms that made solar collectors expensive or not very good performers. Two patents have been applied in Mexico [9, 10] and are continued at PCT [11, 12] This solution was chosen as one of the 20 technologies with most commercialization potential in the State Nuevo León in Mexico by a joint program between government of the state of Nuevo Leon and the Center for of University of Texas in Austin (INVITE). These solar collectors are being produced at the new created enterprise UltraEnertech S.A. de C.V. which received a grant from the Technological Innovation Fund of the Mexican Government CONACYT.

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