Conference Proceedings

EuroSun 2016
Palma de Mallorca (Spain), 11 – 14 October 2016

Analysis of results of a parabolic concentrator's pipe receiver to heat air for drying process of black tea in Cusco, Peru

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Abstract

The objective of the design is to solve the problem of shortage of fuel for drying process in a black tea conditioning factory, through the use of solar thermal concentration with the adaptation of the receiver tube of a linear parabolic concentrator for heating air. This is part of a pilot project to develop and implement in tea enterprise AGROINKA SAC a prototype cogeneration system with solar thermal energy, made of 6 lines of 10 concentrators (60 linear concentrators). The company AGROINKA is in a rural area of the region of Cusco. It has little access to other possibilities of thermal energy resources and technologies for different processes of his production chain of black tea. It is an area dedicated to the processing of tea to supply 80% of the market in the country and 750 families depend on tea production. This paper describes the behavior of hot air in the receiver pipe along a line of 10 concentrators. The results of this paper correspond the winning project of the National Fund for Research and Development Competition for Competitiveness – FIDECOM (for its acronym in Spanish); entitled "Development and integration of a cogeneration system with solar thermal energy for processing of black tea in the Cusco region" 210-FINCyT-FIDECOM -PIPEI-2012.

Keywords: thermal solar energy, drying, tea, Cusco, rural sector, productive use

1. Introduction

The Support Group for the Rural Sector (GRUPO PUCP) is an operating unit of the Department of Engineering at the Pontificia Universidad Católica del Perú (PUCP) founded in 1992. We work to develop appropriate technologies using renewable energy for the rural sector. The project "Development and integration of a cogeneration system with solar thermal energy for the processing of black tea in the Cusco region" was developed in partnership with the company AGROINKA of Cusco.

The processes for obtaining black tea from the Camellia sinensis's leaves are: withering, by leaving the leaves rest for a day in a dry and dark place; cutting, where the leaves are crushed to initiate the oxidation process; fermentation, which gives the black color to the black tea; drying, to remove the moisture and to stop fermentation; and classification.

For the drying process the enterprise uses industrial furnaces, which are fed with wood, in low energy efficiency, resulting the low productivity and high consumption of fuelwood. Then hot air is injected at a temperature between 80 °C and 90 °C to the drying chambers. It has been developed and implemented linear parabolic concentrators to replace a percentage of wood used in the drying process. This paper describes the behavior of hot air in the receiver pipe with 5" diameter along a line 10 concentrators.

2. Project

As mentioned, the project was developed in partnership between GRUPO PUCP and the company AGROINKA. Tea or Camellia Sinensis is originally from Asia but today it can be found in tropical and subtropical regions around the world. Depending on the processing of Carmellia Sinensis' leaves, many

doi:10.18086/eurosun.2016.02.08 Available at http://proceedings.ises.org

types of tea can be obtained with different scents and flavors.

The area has a diverse agriculture by the various ecological floors and microclimates. They can be found in a 2.5 hours' journey from the mountain "Veronica" (4316 m) up to the low jungle in the district of Quillabamba (1050 m). The town of Huyro, where the project took place, is located in the district of Huayopata in the province of La Convención. To reach the town you need to make a 3.5 hours trip from the city of Cusco. According to coordinates, the location is on the south latitude 12 ° 0'23 " S (-13.01), West Longitude: 72 ° 33 '. 25.8 "W (-72.56) and is located at an altitude of 1562 meters above sea level. This area has been identified with an excellent tropical climate for tea production, as well as other products like coffee, cinnamon, fruits, etc.

The company uses 400 truckloads of firewood per year, equivalent to 4000 m3 of wood at a cost of 5.00 soles (approximately $1.5) per kg. For the drying process they use 2 furnaces, which are fed with firewood for heating the air. Then this air is injected at temperatures between 80° C and 90° C to the drying chambers (one fluidized bed and one orthodox). This process reduces the moisture of the tea leaves and stops the fermentation process which gives the characteristic color to the black tea.

The company doesn't have access to other fuel for thermal energy. But they are also aware that its high consumption generates environmental impacts like pollution and deforestation, affecting the landscape, the biodiversity, soil fertility and by increasing the likelihood of landslides.

The design was implemented using a clean and sustainable technology that serves as an alternative to firewood. This prototype system consists of a solar thermal power cogeneration composed by 3 modules of 20 linear concentrators (60 linear concentrators in total). The system is integrated to one of the furnaces which permits the use of hybrid system. Unlike other solar thermal energy, this design does not use a heat exchanger and the air is injected directly into the oven. There's no need to storage the hot air, as the company works up to 3 shifts during the year.

Fig. 1: The solar concentrator's installation in Yanayaco, Cusco, Perú

Fig. 2: Panoramic view of the solar concentrator's installation in Yanayaco, Cusco, Perú

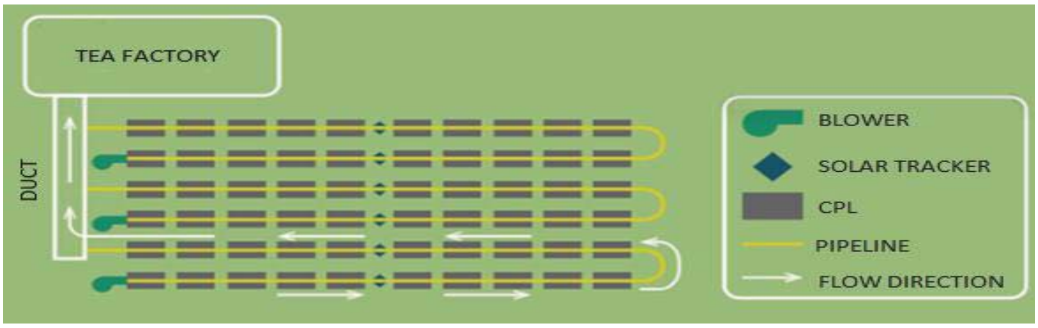

Fig. 3: The solar concentrator's diagram in Yanayaco, Cusco, Perú

Each linear concentrator used anodized aluminum for reflected material and has made with a specific geometry presented in showed in the next table. The 5" pipe was made of carbon steel with a matt black paint coating.

Tab. 1: Concentrator Geometry (Vergara Dávila & Hadzich Marín, 2014)

Description		Units
Semi straight side length	0.530	m
Concentrator Height	0.201	m
Diameter of the pipe	0.127	m
Concentrator length	2.4	m
Concentrator aperture size	2.544	m
Concentrator aperture angle	3.0639	rad
Semi-apparent angle of the sun equal to 16'	0.00465	rad
Pipe Height (different than focus line height)	0.2216	m

3. Methodology

To cover the demand of thermal energy, linear parabolic concentrators were used to generate hot air with the air flowing through the receiver tube making possible working without a heat exchanger. The innovative part of the system is that the air functions as the fluid that flows through the pipeline. However, this carries some difficulties, such as the size of the receiver pipe used which as being too big, it cannot work with a glass tube as insulation. The different air behaviors due to speed flow of the air is also a complication dealt with in this project.

We tested a line of 10 concentrators that reaches the approximate distance of 26 meters. We took data from the inside of the receiver pipe to obtain the temperature curve for the air at different speeds and these tests were repeated with and without insulation on the top of the pipeline.

To obtain information from the behavior of air in the receiver pipe without and with insulation, 11 holes were made along a line of 10 concentrators, where a bimetallic thermometer was introduced.

Additionally, during the test stage, 2 more holes were made in a second line or returned line from the receiver pipe (10 concentrators). The first one at the start point of second line's receiver pipe and the second one at the end of the second line receiver pipe or entry point to the duct to tea factory.

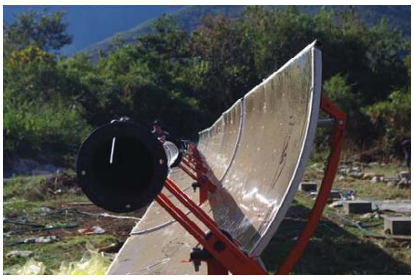

Fig. 4: Section view of the receiver pipe

The Weisz's bimetal thermometer was used. It has a temperature range of 10 ° C to 150 ° C.

Fig. 5: Weisz's bimetal thermometer

On parallel to the temperature's measurement, the beam irradiance was measured. This measurement was made using an irradiance measurer by the brand R & S Renewable Energy Systems. First, we measured global irradiance and subsequently diffuse irradiance. The difference between the two irradiances gives us as a result the beam irradiance.

Fig. 6: R&S Renewable Energy Systems's irradiance measurer

Kestrel brand equipment was used for measuring the air velocity inside the receiver pipe. This was placed at the end of the pipeline.

Fig. 7: Kestrel's air speed measurer

4. Results

Through data collection, temperature curves could be obtained and also the delta of temperature between each sampling point of the receiver pipe with and without insulating varying the air velocity.

Initially air measurement was performed with a speed of 3 m s-1 inside receiver pipe without insulation.

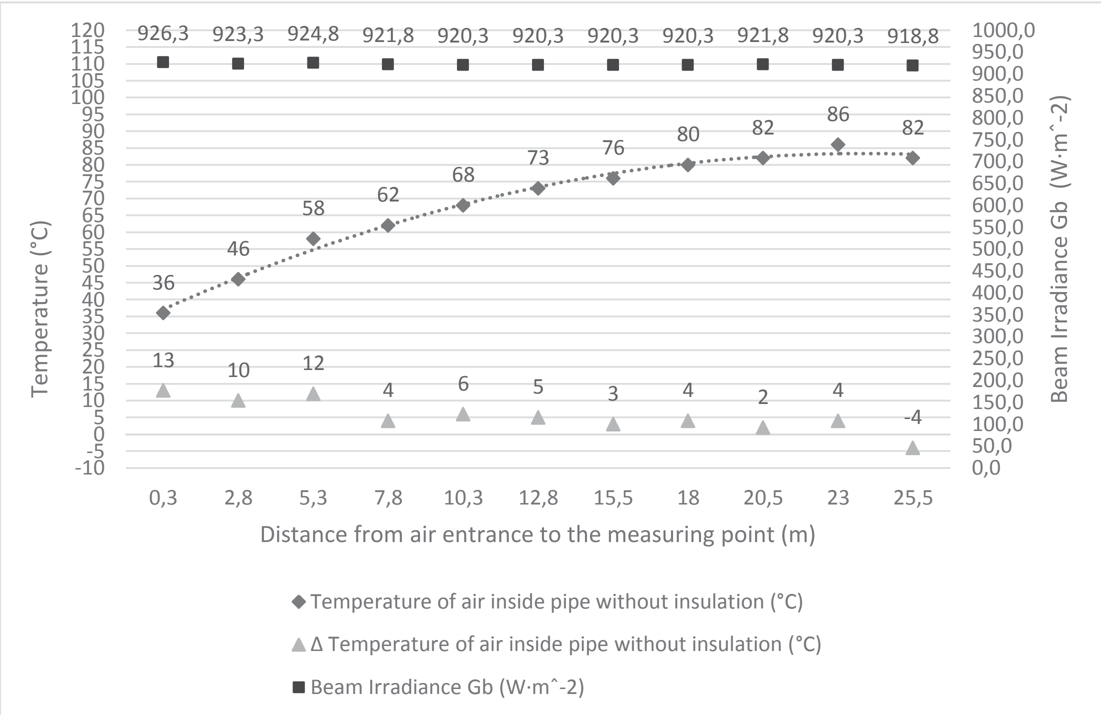

Fig. 8: Behavior of air into the receiver pipe without insulation to 3 m s^{-1}

It can be seen in Fig. 8, that in the first meters the delta of air temperature is higher subsequently it decreases. At 23 m in the receiver pipe the air temperature drops from 86 ° C to 82 ° C. The maximum temperature that air could reach was 86 ° C into the pipe.

Making use of a thermal imaging camera, images of the receiver pipe were taken. As shown in Fig. 9 the temperature is higher in the area where the receiver tube receives sunlight reflected by the concentrators, however, the temperature at the top reached around 60 ° C.

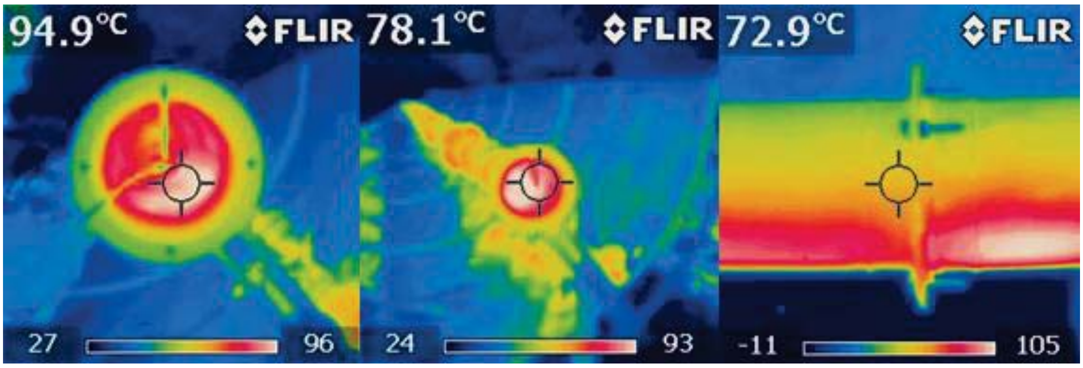

Fig. 9: a) sectional view of the receiver pipe without insulation; b) view of receiver pipe without insulation ; c) side view of receiver pipe without insulation

Afterward it was considered to place on the top of the receiver pipe of 5" diameter, a fiber insulation glass with a top cover in case of rain. The tests were repeated with a speed of 3 m s-1.

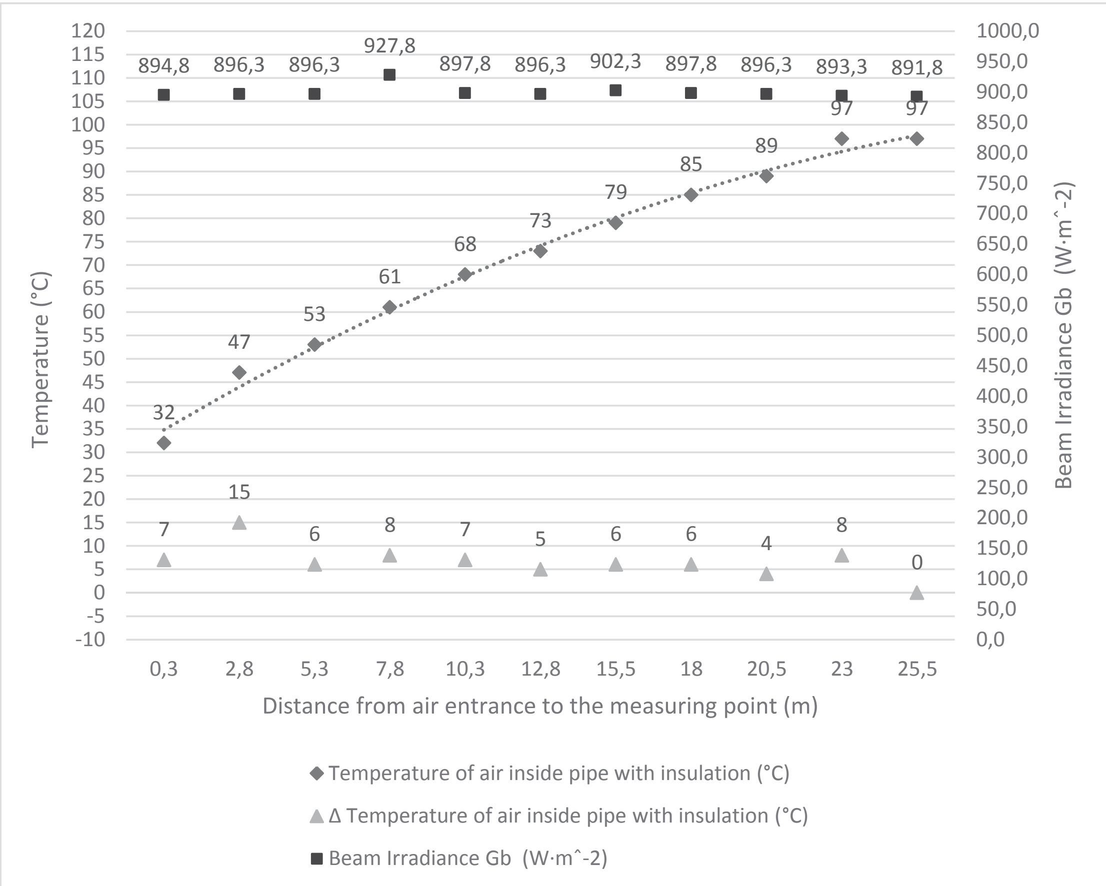

Fig. 10: Behavior of air into the receiver pipe with insulation to 3 m s^{-1}

Can be seen in Fig. 10 in the first meters, the delta of air temperature is higher. However delta of air temperature remains constant along the receiver pipe. As in the previous case, from 23 m of the receiver pipe, air temperature decreases. The maximum temperature that air reached was 97 ° C into the pipe.

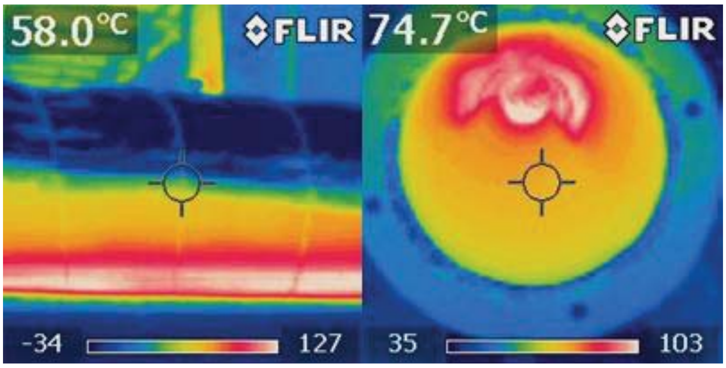

Fig. 11: a) lateral view of the pipe with insulation; b) sectional view of the receiver pipe with insulation

It can be seen in Fig. 11 the thermographic image of lateral and sectional view of the receiver pipe after fitting with insulation.

For better comparison of the behavior of air temperature, both insulated and non insulated receiver pipe were integrated in Fig. 12.

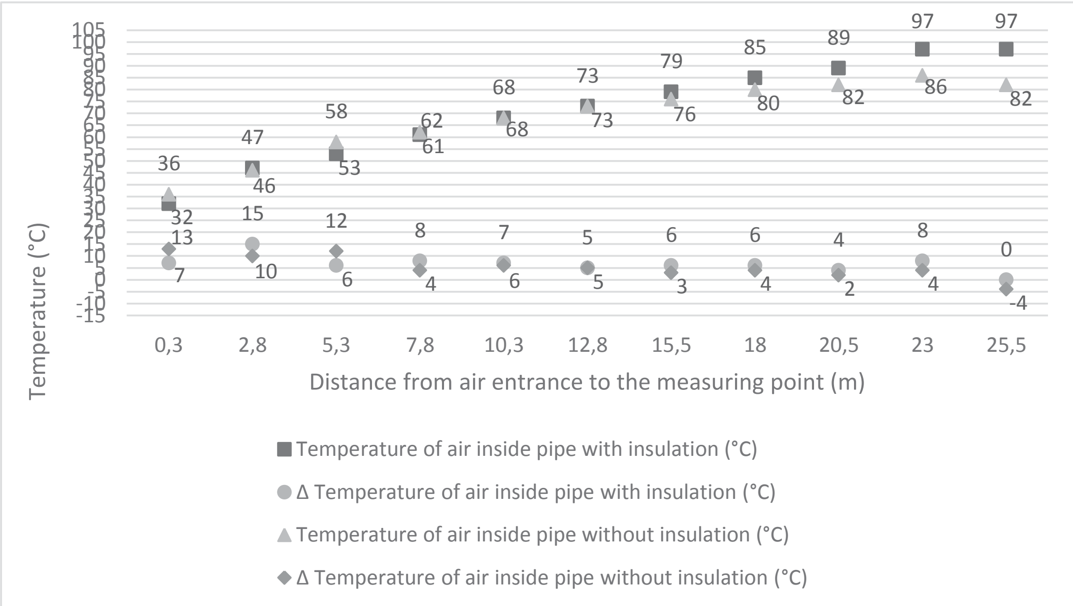

Fig. 12: Behavior of air into the receiver pipe receiver with and without insulation to 3 m s^{-1} air velocity

As shown in Fig. 12 from the 15.5 m of the receiver tube, the air in the insulation system reaches higher temperatures.

It's important to mention that in the second line, for a velocity of 3 m/s with insulation, we obtained in the start point of the second line's receiver pipe (first hole) a temperature of 88°C. This is because, the pipe curve that connect first line with second line has a heat loss of 10 ° C. Meanwhile, in the end of the second line receiver pipe (second hole) or entry point to the duct, we archived a temperature of 108°C.

This showed us, that total delta temperature of air on the first line with 3 m/s and insulation is around 65°C, meantime that total delta temperature of air on the second line with 3 m/s and insulation is around 20°C. In consequence, due to economic and financial viability the rest of testing stage was focused on the first line.

The same procedure was repeated with the receiver pipe insulated by varying the air velocity to 8.5m s^{-1}. This variation was conducted by opening the gate of the blower air flow.

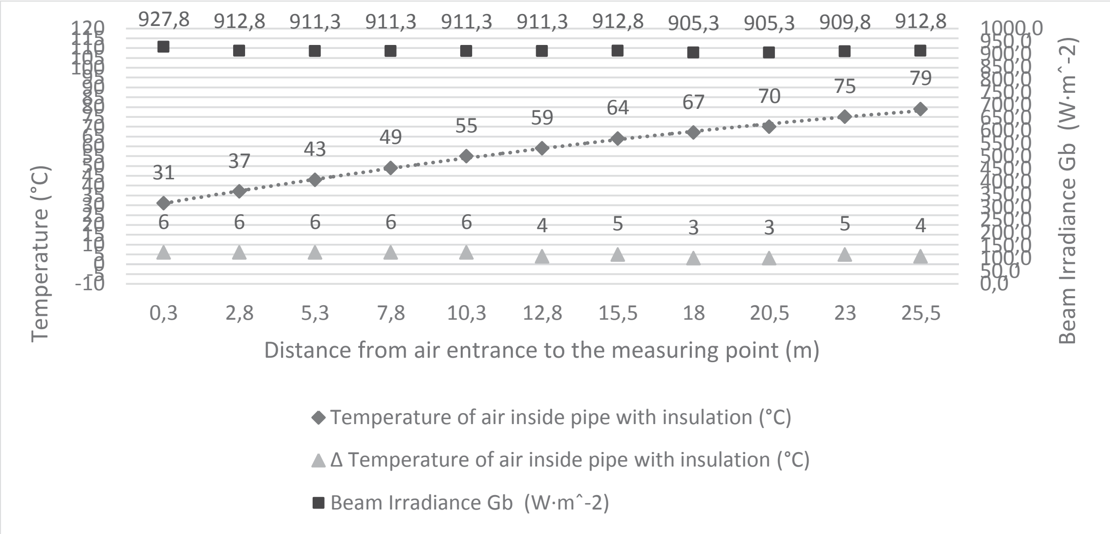

Fig. 13: Behavior of air into the receiver pipe with insulation to 8.5 m s^{-1}

It can be seen in Fig. 13 that the delta air temperature is constant from the start, along the receiver pipe. It could reach 79 °C of air temperature inside the pipe with a speed of 8.5 m s^{-1}.

Finally, the same procedure was repeated with the receiver pipe insulated varying the air speed to 14m s^{-1}. This variation was conducted by opening the gate of the blower air flow.

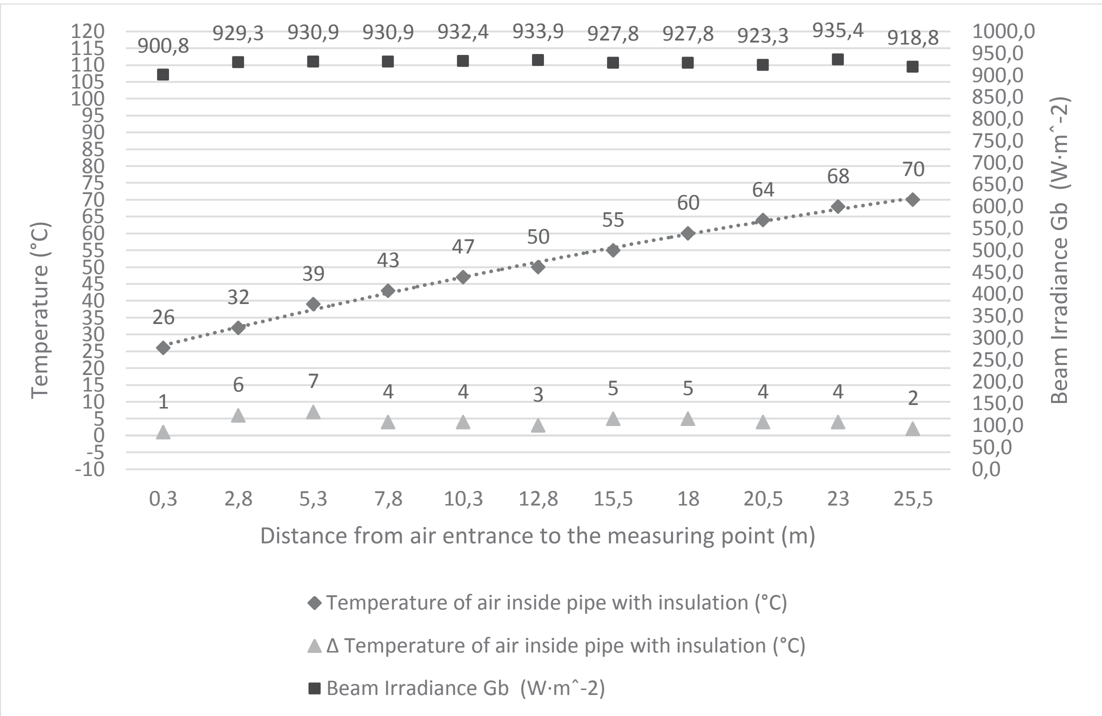

Fig. 14: Behavior of air into the receiver pipe with insulation to 14 m s^{-1}

It can reach 70 °C of air temperature inside the receiver pipe with a maximum speed of 14 m s^{-1}.

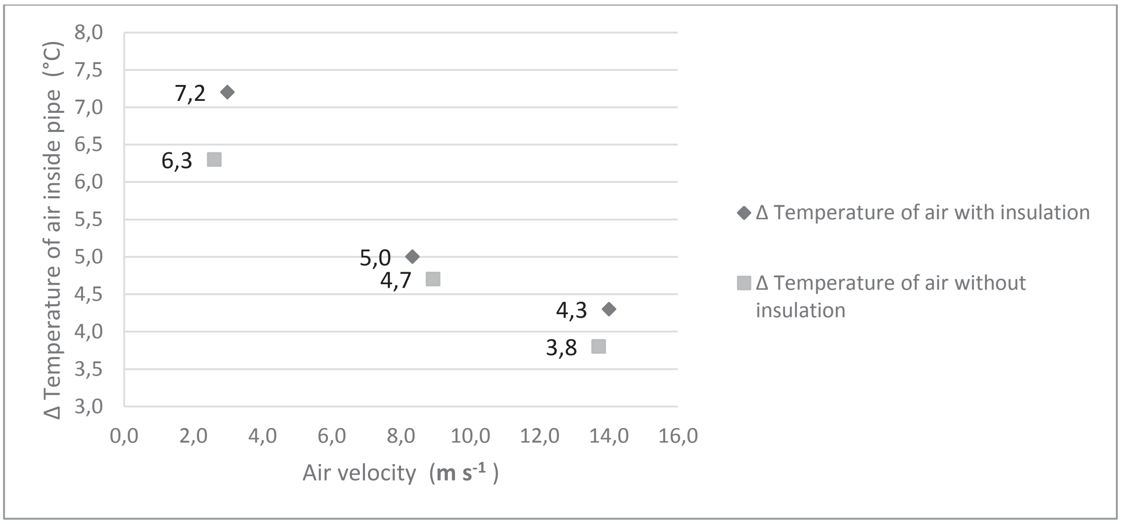

Fig. 15: Δ Temperature of the air in the pipe with and without insulation depending on the speed

It can be observed that the higher the air's velocity gets, the lower delta of temperature of air is obtained, and the delta of temperature of air in the receiver pipe with insulation is greater than without insulation.

5. Conclusions

It can be concluded that a large difference in temperatures can be reached when comparing receiver pipe with and without insulation. For example, in Fig. 12 we observe that at the last meters the receiver pipe with insulation has a difference of 15°C compared to the receiver pipe without insulation. In addition, the receiver pipe with insulation is better to reach higher temperatures spite of different speeds how we observe in Fig. 15

Likewise, depending on the speed with which the air is transported, a variation in the temperature delta is obtained, mainly because of heat losses depending on the flow characteristics.

It can also be concluded that using air as the carrier fluid with 3 m/s of air velocity, we can achieve a temperature of 97 °C at 25.5 meters inside the receiver pipe with 5 inches of diameter and insulation in Fig. 10.

6. References

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