Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25855

195 (2020) 267–274
August

Comparative analysis of hexagonal boron nitride coated on copper winding in the saline-based heat pipe

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Received 6 July 2019; Accepted 16 March 2020

ABSTRACT

Parabolic solar trough receiver is the key component of the parabolic trough solar power production. The receiver is a hollow cylindrical structure, which absorbs the heat reflected from the parabolic solar trough and passes the absorbed heat to the working fluid. It has a decisive influence on the thermal performance of the power plant. In the receiver pipe, the whole heat gets concentrated at one part of the receiver pipe, which increases the thermal strain on the receiver pipe. This phenomenon leads to the structural damage of the receiver. The objective of this experiment is to distribute the heat equally along the surface area of the receiver pipe of 2,000 mm length, 76.2 mm outer diameter, and 73.2 mm inner diameter. The receiver pipe contains water as the working fluid by winding with and without a copper tube of 5 mm outer diameter and 3 mm inner diameter in which the Therminol 55 issued as working fluid. The strain values across the selected points are measured using thermocouple. The hexagonal boron nitride (h-BN) is spray-coated for decreasing the thermal expansion. Scanning electron microscopy analysis and energy dispersive X-ray analysis tests are taken for the effect of measuring the effect of the spray coating. The thermal strain values are plotted along the entire length of the pipe. From the results, it is observed that the strain value is always less in the receiver pipe is wounded with a copper coil that is lesser than that of the receiver pipe without the copper coil. A receiver pipe wounded with copper coil has strain values more than that of the strain of receiver pipe sprayed with h-BN and wounded with copper coil respectively at any point on the length of the receiver.

Keywords: Receiver pipe; Working fluid; Hexagonal boron nitride; Thermal strain; Thermal expansion; Copper coil

1. Introduction

The alternate source of energy, solar is oriented with high temperature that uses the transformation of sunlight based radiation to drive the high-temperature motor that fills in as the prime mover for an electric generator. The concentrated sunlight based power (SBP) and power creation that depends on petroleum product ignition, both depend on the change of high-temperature vitality to mechanical vitality than to electrical vitality. We have four principle advancements that use the concentrated sun oriented warm vitality: (i) solar pinnacle frameworks, (ii) parabolic trough frameworks, (iii) Sterling sunlight based dish frameworks, and (iv) straight Fresnel frameworks. For applications, for example, sun based cooker or water siphoning, SBP is legitimately utilized. In solar explanatory authority frameworks, the mirrors are mounted on the supporting structure to reflect and concentrate the sunlight based radiation to the focal point of the illustrative trough (the collector) to accomplish the necessary temperatures. There are numerous parameters on which the plan of illustrative trough depends, for example, sun-powered dispersion flux,

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reflector material of the concentrator, the distance across of the explanatory trough concentrator, measuring the gap territory of the concentrator, central length of the allegorical trough, the point of convergence breadth, estimating the opening zone of the collector, safeguard material of the recipient, geometric or zone fixation proportion, and edge. The gatherer execution is steady and the proficiency of the authority is high and shows just a slight drop at high working conditions [1]. The deviated qualities, for example, non-uniform warmth motion and whimsy setup directly affect the neighborhood heat move process [2]. The impacts of varieties in the thicknesses of the fume channel and the presentation of both the two models of warmth pipes, for example, circle and the level plate is explored and thought about. The elements restricting warmth pipe productivity are recognized and gives the outcomes that show the circle formed warmth pipe while using a little surface territory and being progressively versatile to a few application regions, essentially expands the warmth moveability per unit surface zone contrasted with rectangular level plate heat pipe [3]. Expository answer for different factors, for example, temperature, fume speed and weight disseminations are gotten by utilizing top to bottom necessary technique [4]. The warmth pipe sunlight based gatherer has a wide scope of uses, for example, residential usage, organization reason, and so on [5]. There is a sort of pipe utilized practically speaking that is emptied tube sun based pipe which has been presented for execution improvement contrasted and the customary level plate heat pipe [6]. There are a few disadvantages in the emptied cylinder sunlight based gatherer, for example, the temperature varieties ought to be controlled on the grounds that in local applications the temperature required for activity is little around 100° yet the cleared cylinder heat pipe effectively crosses the most extreme range which harms the supplies and erodes so fluid is utilized to control the temperature varieties [7]. If there should arise an occurrence of moderately low warmth list for working liquid the uniform high-temperature transfer relies upon the dynamic thickness, and in the event that the warmth file esteem is low, at that point it relies upon heat conveying ability to work liquids [8,9]. Optical models, for example, Monte Carlo method, finite volume method, change photon energy method are developed for accomplishing the most extreme effectiveness at various geometric parameters [10]. Another serpentine plan of the compound illustrative concentrator was planned which improved the effectiveness of almost 60.5 rates [11]. The present paper intends to decide the conceivable uniform warmth conveyance by methods for copper twisting with working liquids inside it, the analysis was performed in encompassing conditions; the exhibition of the pipe is contrasted and without copper winding.

2. Material

2.1. Receiver pipe

SS304 is utilized as a beneficiary pipe in this undertaking. The composition and the properties of SS304 are shown in Tables 1–3. It is accessible in the more extensive scope of items, this structure competes with other stainless steel grades. Evaluation of 304L, the low carbon variant of 304, doesn't require post-weld strengthening as it is broadly utilized in overwhelming check parts (over about 6 mm). Evaluation of 304H with its higher carbon content discovers application at raised temperatures. The austenitic structure gives very long durability, even when the temperature is very down to the cryogenic temperatures.

Evaluation of 304H has higher quality at raised temperatures so it is frequently utilized for basic and weight containing applications at temperatures above around 500°C and up to around 800°C. 304H gets sharpened in the temperature scope of 425°C–860°C; this isn't an issue for high-temperature applications, yet brings about diminished watery consumption obstruction. Arrangement treatment (annealing) – heat to 1,010°C–1,120°C and cool quickly. These evaluations can't be solidified by warm treatment.

2.2. Copper coil

In this experiment, copper coil is used to flow the heat transfer fluid. The coil has an outer diameter of 5 mm and an inner diameter of 3 mm.

Copper has incredibly valuable properties, for example,

- Good electrical conductivity.
- Good warm conductivity.
- Corrosion opposition.

The copper is a great transmitter of high temperatures. To conduct heat from one end to another end unvaryingly copper is the best conductor when compared with the silver. Hence, so the copper tube is used for helically winding the receiver pipe for distributing the heat from one point to another. Design parameters for the coil are given below:

$$\text{Helix angle } (\alpha) = \text{Tan-1}(\pi \times D/p) \quad (1)$$

$$\text{Pitch of the coil } (P) = (L–d)/n \quad (2)$$

$$\text{Total length of coil wounded (LT)} = L1 \times n \quad (3)$$

where D is the mean diameter of the coil; L is the length between two turns; $L1$ is the length of the coil in one turn (circumference).

Table 1
Composition ranges for 304-grade stainless steel

%	304L	304H	304
Cr	17.5–19.5	17.0–19	17.5–19.5
Fe	Balance	Balance	Balance
Si	0–1	0–1	0–1
P	0–0.05	0–0.04	0–0.05
Mn	0–2	0–2	0–2
Ni	8–10.5	8–11	8–10.5
S	0–0.02	0–0.02	0–03
N	0–0.11	0–0.10	0–0.11
C	0–0.03	0–0.08	0–0.07

Table 2
Mechanical holdings for alloys

Grade	Tensile strength (MPa) min	Elongation (% in 50 mm) min	Hardness		Yield strength 0.2% proof (MPa) min
			Rockwell B (HR B) max		Brinell (HB) max
304L	485	40	92	170	201
304H	515	40	92	205	201
304	515	40	92	205	201

Table 3
Physical properties of 304-grade stainless steel in the annealed condition

9Grade	Elastic modulus (GPa)	Mean coefficient of thermal expansion (µm/m/°C)			Thermal conductivity (W/m-K)		Electrical resistivity (nΩ m)	Specific heat 0°C–100°C (J/kg K)	Density (kg/m³)
		0°C–100°C	0°C–315°C	0°C–538°C	at 500°C	at 100°C			
304/L/H	193	17.2	17.8	18.4	21.5	16.2	8,000	500	720

Table 4
Acreage of working fluid

Composition	Synthetic hydrocarbon blend
Most extreme film temperature	335°C (635°F)
Most extreme mass temperature	290°C (550°F)
Expanded greatest use temperature	315°C (600°F)
Copper consumption	<<1a
Siphon capacity, at 300 mm²/s (cSt)	–8°C (17°F)
Siphon capacity, at 2,000 mm²/s (cSt)	–28°C (–18°F)
Streak point, (ASTM D-92)	177°C (350°F)
Auto start temperature (ASTM E-659)	343°C (650°F)
Auto start temperature (DIN 51794)	366°C (691°F)
Pour point (ISO 3016)	–54°C (–65°F)
Least fluid temperatures for completely created tempestuous flow	(NRe > 10,000)
Warmth of vaporization at maximum use temperature	228 kJ/kg (98.1 Btu/lb)
Kinematic consistency at 100°C (ASTM D-445)	3.52 mm²/s (cSt)
Fluid thickness at 25°C	868 kg/m³ (7.25 lb/gal)
Normal sub-atomic weight	320
Pseudo basic temperature	512°C (953°F)
Pseudo basic pressure	13.2 bar (191 psia)
Appearance	Clear, yellow fluid
Dampness content, most extreme	150 ppm
Dielectric steady at 23°C	2.23
Typical bubbling point	351°C (664°F)

2.3. Heat transfer fluid

Therminol 55 is a heat temperature transfer liquid manufactured for the purpose of moderate temperature applications. The intention is to utilize the subsidiary heating method with the minimum and maximum pressures in the heating framework. Therminol 55 has the capability to resist up to 4,000 centigrade without meeting any convergence in its fluid flow properties.

Hence, Therminol 55 is used as the heat transfer fluid for distributing the heat uniformly. The properties of the working fluid are shown in Table 4.

3. Experimental method

The experimental setup consists of heating strips, receiver pipe, copper winding, working fluid circuit, and heat transfer fluid circuit. The heating strip is made of chromium steel as shown in Figs. 1–3. Strip heaters are used principally for convection-type air heating and clamp-on installations. When selecting strip heaters for two important factors must be considered, one is the proper sheath material for resisting any rusting and oxidizing inherent in the process or environment and the second is for withstanding the sheath temperature required. Standard sheath materials are rust resisting iron, chrome steel, and Incoloy (NS Series only). Stainless steel and Monel sheaths are available at an additional charge. Maximum work and sheath temperatures are given below. The watt density of the element, or watts per square inch of the heated area can be higher for heating air, metals, and other heat-conducting materials.

In this experiment there are three types of setups:

- Receiver pipe without the copper coil.
- Receiver pipe wounded with copper coil.
- Receiver pipe sprayed with hexagonal boron nitride (h-BN) and wounded with copper coil.

The working fluid in the storage tank-1 is allowed to flow to storage tank-2 through the receiver tube which is wounded with copper tube as shown in Fig. 4. The heat transfer fluid flows through the copper tube from the heat transfer fluid tank to the collector tank. The receiver pipe wounded with the copper tube is heated by the heating strip. The main purpose of using the copper tube to wound the receiver pipe is that it has good thermal conductivity, good heat flow rate, and less corrosive.

In this experiment, water is taken as the working fluid which flows through the receiver pipe and Therminol 55 is used as the heat transfer fluid which flows through the copper coil wounded helically over the surface of the receiver pipe. Instead of concentrated solar power, the heating strips are used for heating the whole setup. A maximum of 400°C can be achieved by using the heat strips. The whole setup is heated for three different temperatures 200°C, 250°C, and 300°C. The temperature is measured at two opposite points, one at the line of contact with heat strip and another at the opposite side along the length of the receiver pipe by using the *K*-type thermocouple. The readings are taken on the 5th day and 20th day.

4. Results and analysis

4.1. Scanning electron microscopy analysis

In this experiment, the scanning electron microscopy (SEM) Analysis of the SS304 with boron nitride coating after annealing is discussed. The properties of h-BN are shown in Table 5. The main aim of using the boron nitride is to increase the thermal conductivity and to decrease the corrosion at elevated temperatures. Recently, two-dimensional, layered materials such as graphene and h-BN have been identified as interesting materials for a range of applications. The stainless steel with coatings exhibited improved corrosion resistance. h-BN is a two-dimensional layered material that can remain stable at 1,500°C

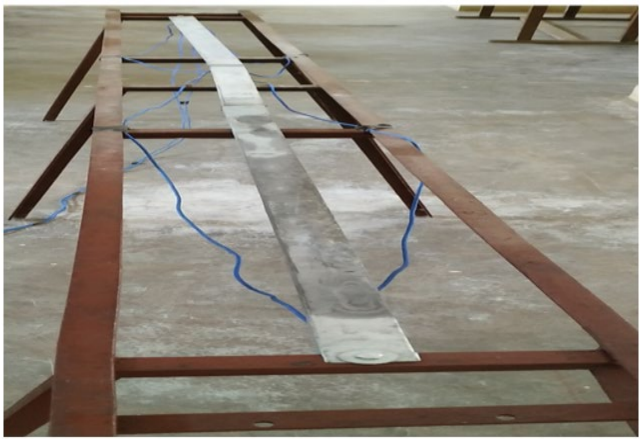

Fig. 1. Heating strips.

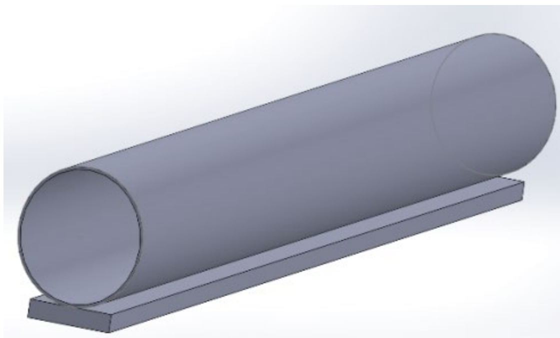

Fig. 2. Receiver pipe without copper winding.

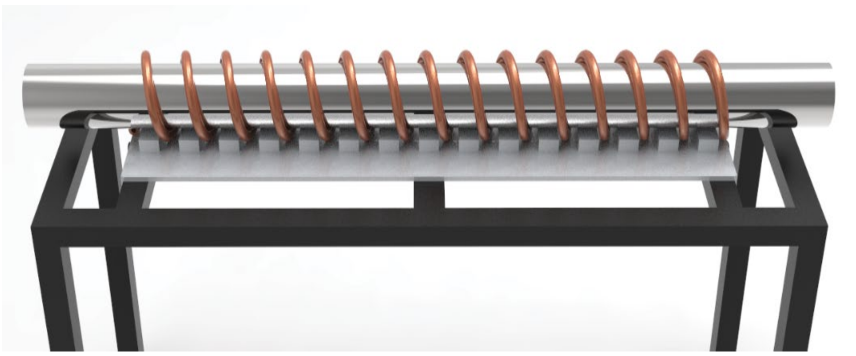

Fig. 3. Experimental setup in a three-dimensional view.

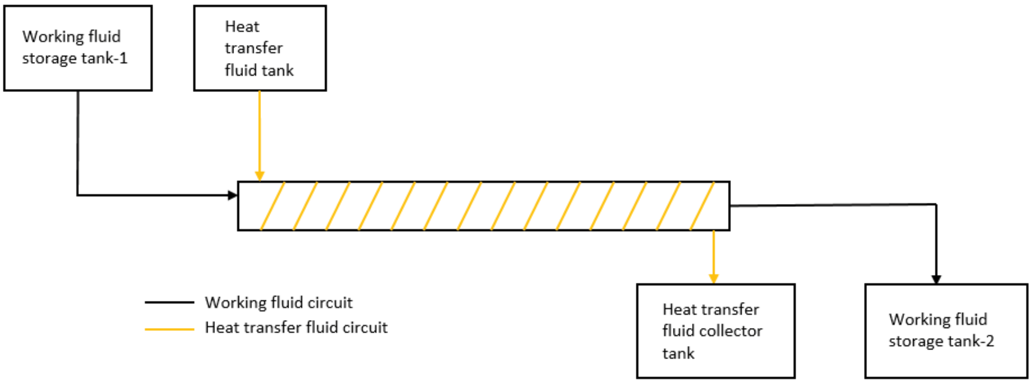

Fig. 4. Block diagram of the experiment.

Table 5
Properties of h-BN

Material	h-BN
Density (g/cm^3)	~2.1
Bulk modulus (GPa)	36.5
Thermal conductivity (W/(m-k))	600
Thermal expansion (10^{-6}/°C)	11
Refractive index	1.8
Magnetic susceptibility (μemu/g)	–0.48

in air and does not react with most chemicals. Boron nitride coatings are prepared from borazine as the single-source precursor containing stoichiometric boron and nitrogen by hot-wall chemical vapor deposition in a low deposition temperature at range from 800°C to 900°C, with a total pressure of 1 kPa.

Fig. 5 represents the SEM analysis of SS304 material after annealing with boron nitride spray. It represents the molecular structure of SS304 sprayed with boron nitride where it has N, O, Fe, C, Si, Al, and Cr content in it. Due to spraying the boron nitride on the pipe material a dry, durable protective film is quickly formed. It releases excellent lubricating and protective effects – even at high temperatures. It is seen that B1.0N0.9-NPs are generally steady in the air underneath 850°C in which just oxidation of the NP surface continued. Above 850°C, the powders began to emphatically respond with air because of mass oxidation. The above diagram Fig. 6 speaks to the quantitative outcomes by weight level of the components present in the SS304 example with boron. The iron(Fe) present in the SS304 is high as in Fig. 7 which results in consumption at high temperatures. Also, chromium in SS304 is to expand protection from oxidation. Since these opposition increments are more, chromium is included. h-BN gives a stamped level of general erosion opposition when contrasted with steels with a lower level of chromium.

4.2. Experimental analysis

The strain at different temperatures is calculated by using the temperatures at two opposite points along with the length of the pipe by using the following formula:

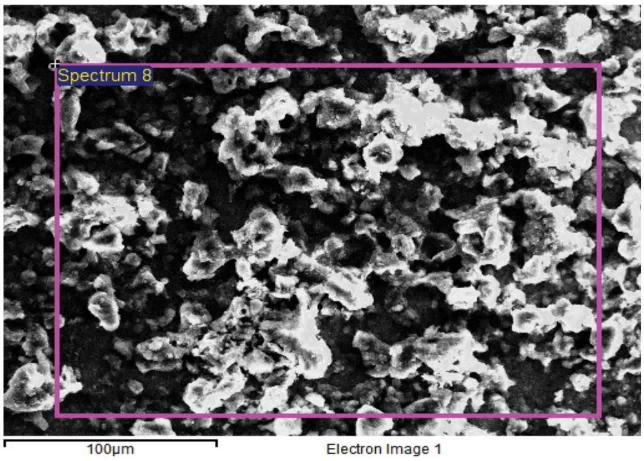

Fig. 5. SS304 with boron nitride.

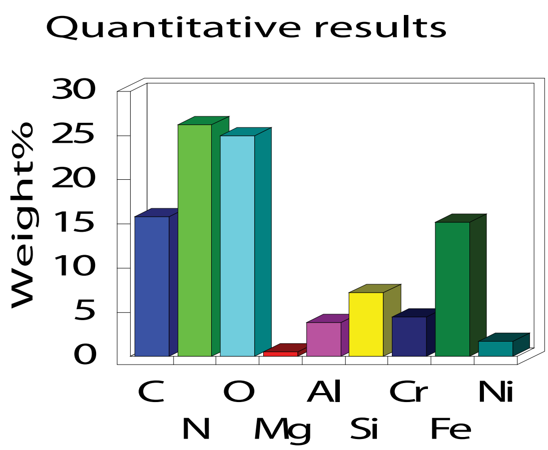

Fig. 6. Elements in SS304 with boron nitride.

$$e = \alpha\,\Delta T = \alpha\,(T2 - T1) \quad (4)$$

where e is the strain; α is the thermal expansion (×10°C–6°C); ΔT is the change in temperature (°C).

This experiment is carried out continuously for 25 d. The readings are taken on 5th and 25th day at 200°C,

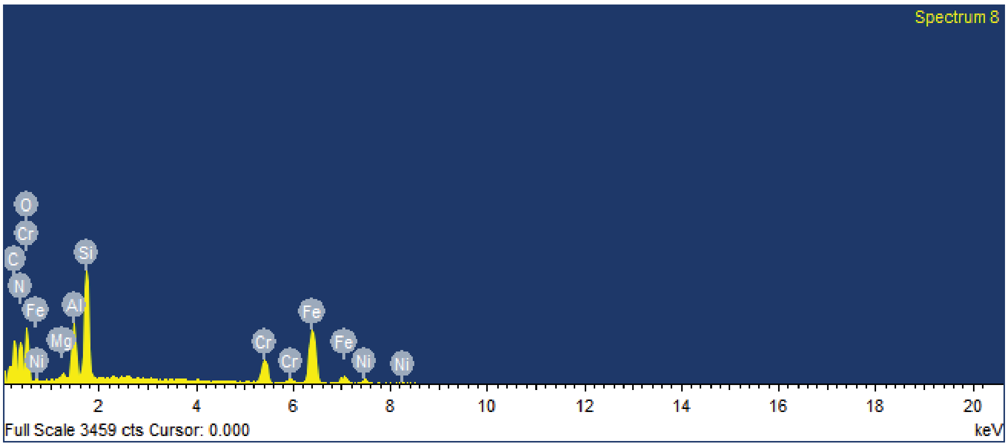

Fig. 7. Energy dispersive X-ray analysis.

250°C, and 300°C. In the wake of watching the temperature readings are organized and strain has been determined. The strain vs. length graphs for receiver pipe without the copper coil, receiver pipe wounded with copper coil, receiver pipe sprayed with h-BN and wounded with copper coil are plotted accordingly in the 5th and 20th days for 200°C are compared in Table 6.

A graph plotted as in Fig. 8 for strain variation along the length of the tube for different kind of attachments, the observation thus shows the strain value is the peak for the receiver pipe without copper winding, the line corresponding for that setup shows the maximum value from the initial stage when compared with rest others.

The observations taken for the temperature 250°C has been tabulated in Table 7, the strain value continues to increase as compared with the previous dates which bring the reduction in the performance, by adding copper winding attachment practically showed some reduction in strain value and it can be improved further by topping it with h-BN spray as in Fig. 9.

The observation for the temperature around 300°C as in Table 8, where the readings are taken up to the peak time 2 pm it is clear that the strain has direct proportion with the temperature of the receiver pipe, and the steps are taken to prevent such negative impact on the performance also noted and plotted graphically as in Fig. 10.

5. Conclusion

The helically wounded copper tube transfers the heat from the high-temperature region to the low-temperature region by flowing the Therminol 55 fluid through it, so that the whole pipe is maintained at the same temperature. The Therminol 55 transfers the heat without any property changes. The h-BN is sprayed in order to decrease the thermal expansion of the receiver pipe. So, that the strain in the pipe is decreased.

Henceforth, from the investigation, it very well may be reasoned that the strain esteem is in every case less in the recipient pipe injured with copper curl is not as much as that of the beneficiary pipe without copper loop. What's more, the strain of beneficiary pipe showered with h-BN and injured with the copper loop is not as much as that of recipient pipe injured with copper curl separately anytime on the length of the collector tube (i.e., 0.4 or 2 m). From the over three charts the strain in the pipe expanded step by step. Now and again, the distinction in strain worth might be insignificant, however not a solitary point exists where

Table 6
Strain at 200°C on 5th and 25th day

Length of the pipe	Without coil (5th day)	With coil (5th day)	With boron nitride and with coil (5th day)	Without coil (25th day)	With coil (25th day)	With boron nitride and with coil (25th day)
0.4	0	0	0	0	0	0
0.6	0.015	0.008	0.005	0.091	0.081	0.0692
0.8	0.034	0.032	0.0224	0.16	0.141	0.122
1	0.04	0.037	0.0266	0.25	0.22	0.177
1.2	0.046	0.043	0.0322	0.31	0.25	0.194
1.4	0.058	0.054	0.0394	0.44	0.34	0.258
1.6	0.064	0.059	0.0443	0.56	0.47	0.383
1.8	0.077	0.073	0.0598	0.66	0.58	0.47
2	0.091	0.086	0.0689	0.701	0.64	0.534

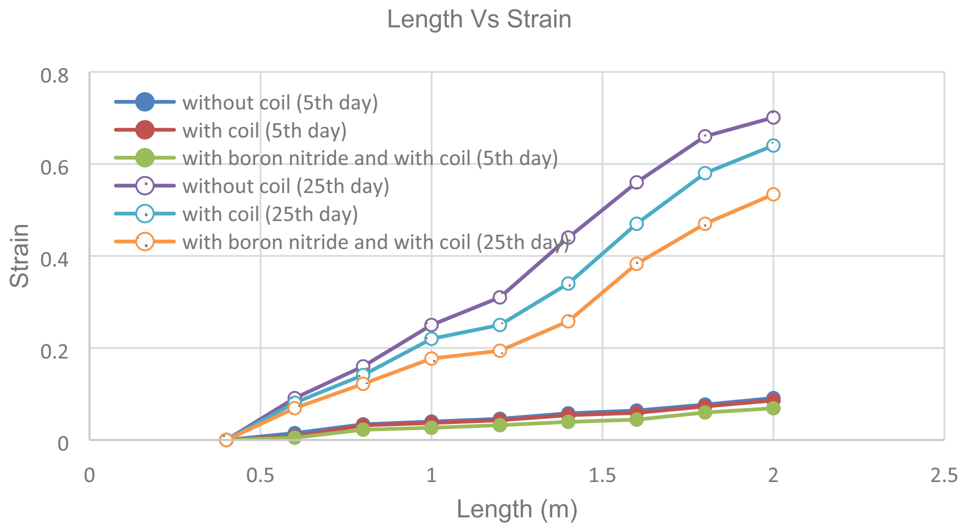

Fig. 8. Strain comparison graph at 200°C.

Table 7
Strain at 250°C on 5th and 25th day

Length	Without coil (5th day)	With coil (5th day)	With boron nitride and with coil (5th day)	Without coil (25th day)	With coil (25th day)	With boron nitride and with coil (25th day)
0.4	0	0	0	0	0	0
0.6	0.02	0.014	0.011	0.1	0.091	0.071
0.8	0.039	0.032	0.0254	0.18	0.163	0.142
1	0.045	0.039	0.0273	0.266	0.22	0.183
1.2	0.051	0.047	0.0349	0.368	0.304	0.221
1.4	0.063	0.058	0.0422	0.521	0.439	0.328
1.6	0.071	0.065	0.0492	0.619	0.53	0.426
1.8	0.082	0.076	0.0602	0.756	0.649	0.543
2	0.097	0.092	0.0713	0.84	0.729	0.597

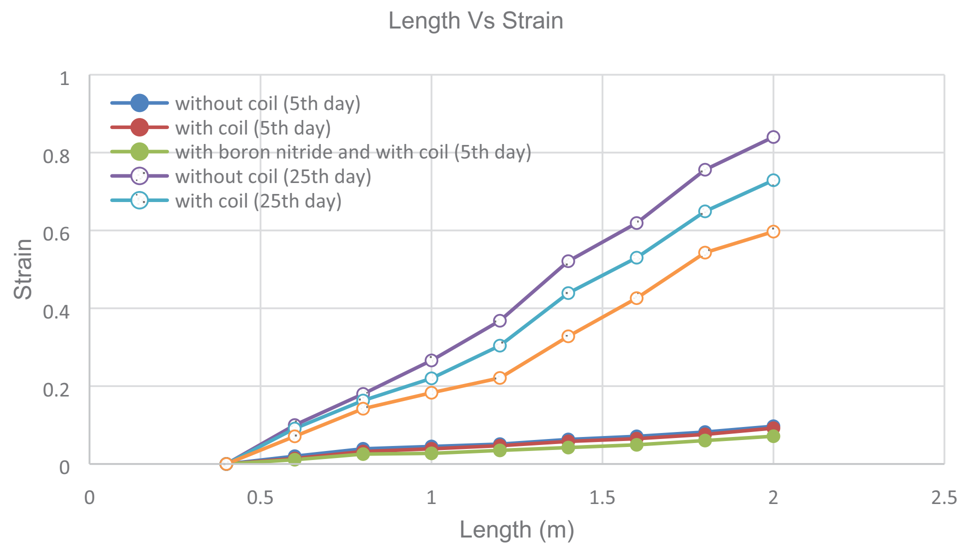

Fig. 9. Strain comparison graph at 250°C.

Table 8
Strain at 300°C on 5th and 25th day

Length	Without coil (5th day)	With coil (5th day)	With boron nitride and with coil (5th day)	Without coil (25th day)	With coil (25th day)	With boron nitride and with coil (25th day)
0.4	0	0	0	0	0	0
0.6	0.031	0.025	0.0184	0.146	0.127	0.0986
0.8	0.044	0.038	0.0278	0.244	0.224	0.187
1	0.053	0.045	0.0349	0.338	0.294	0.265
1.2	0.064	0.051	0.0401	0.426	0.379	0.326
1.4	0.071	0.0604	0.0489	0.574	0.516	0.459
1.6	0.084	0.073	0.0534	0.684	0.647	0.541
1.8	0.093	0.084	0.0647	0.793	0.761	0.688
2	0.11	0.099	0.0754	0.874	0.829	0.734

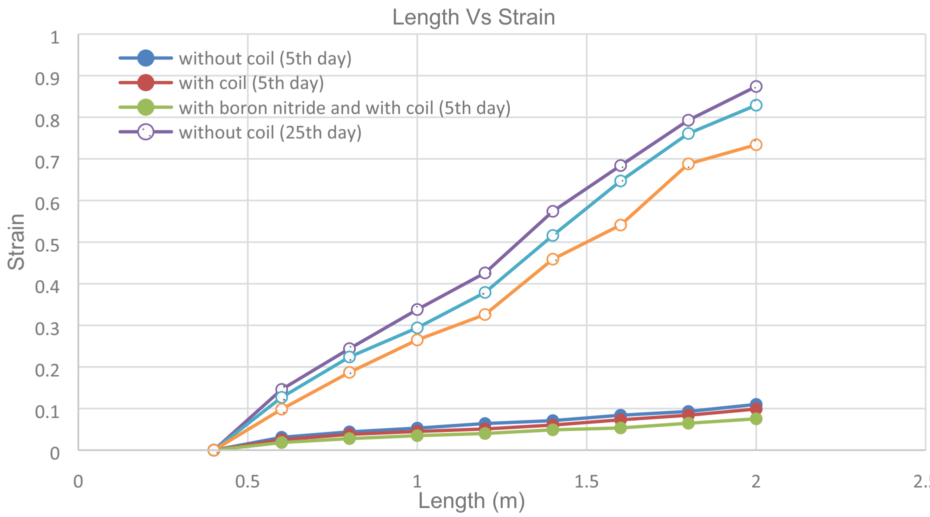

Fig. 10. Strain comparison graph at 300°C.

the strain of straight collector tube is not as much as that of the injured one. And furthermore up to 300°C, surface temperature improvement of sun based recipient tube is best accomplished by h-BN covered injured collector tube. In this way, the warmth is similarly circulated along the outline of the beneficiary to the lesson asymmetric warming of the pipe.

Symbols

CSP	—	Concentrated solar power
D	—	Mean diameter of coil, mm
d	—	Diameter of coil, mm
P	—	Pitch of the coil, mm
T	—	Temperature, °C
α	—	Helix angle, °

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