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Experimental Investigation on Fatigue Behaviour of Solar Receiver Tube under Assymetrical Flux Condition

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Abstract : Fatigue stress is the design criterion when materials are operating under repeated or reversal loading conditions, loading may be mechanical for structural members and thermal for heat exchanging devices. In this paper the variable thermal fatigue loading of solar receiver tube is studied and the suitable geometrical design alternative is proposed. The tubes are heated asymmetrically throughout the day and cooled at the night (loading and unloading), cyclic in nature, since receiver tubes of solar concentrator collector exposed to asymmetrical nature of heat flux, thermal stresses are induced at the junction of uneven expansion. The induced thermal stress added with fatigue loading accelerates the failure due to stress reversal. The endurance limit of conventional linear tube decreases with prolonged exposure to sunlight, and the reduction rate is proportional to operating temperature. This present paper deals within the range of 300℃ and the comparison of endurance limit is made between straight tube and helical coiled tube receiver for 45 days of operation. The reduction is found to be decreased from 260 MPa to 190 MPa for straight tube and from 335 MPa to 296 MPa.
Keywords : Thermal Fatigue, Endurance limit, Helical Coiled Receiver.

1. Introduction:

Jianghui Mao et al. studied the thermo-mechanical fatigue life of automobile engine exhaust pipe, and found that the visco-plastic models yield most reliable TMF behaviour [1], also found that the elasto plastic model fails at high temperature due to relaxation and creep. High temperature fatigue behaviour of Glidcop Al-15 was studied by Abderrazak Daoud et al. [2] and reported that there is a reduction in EL from 300Mpa to 285 Mpa. Flores et al. [3] analyzed the thermal stress of a circular tube receiver and reported that the small diameter tubes show maximum life compared to the large diameter tubes. Myung Jo Jhung et al. [4] studied the FSI analysis on Tee connection piping system and found the fatigue usage factors. Y. Luo et al. [5] studied the allowable flux density of boiling section of receiver tube (Central type) and found the effect of receiver tube pressure on the fatigue and thermal stress. Very important aging test on parabolic trough receiver is carried out by Pernpeintner et al. [6] in the temperature range of 80-100 K for various hours and subjected to 20,000 cycles and reported the durability ranking for trough collectors. Kai Bauerbach [7] et al. studied the crack closure behavior under thermal cyclic loading with initial damage and without initial crack. Fatigue fracture of solar tower receiver using molten salt and thermal stress is studied by [8-10].

2. Experimental setup test specimen:

(a) **(b)**

(c)

(d)

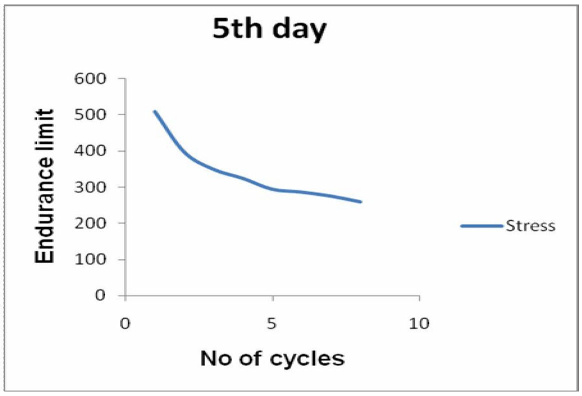
Fig 2.1 a) Heating and flow arrangement b) heated tube c) straight tube specimen d) helical tube specimen.

The receiver tubes heat transfer and fluid flow mechanisms are simulated under laboratory condition for an outlet temperature of $300^{\circ}C$ using thermal oil as a working fluid 2.1 a). The experimental setup is build based on the work carried out by Simone Sissa et al. [11] on engine exhaust. Fig 2.1 b) Shows cut section of specimen after conducting experiment for 45 days then the specimen is taken to fatigue testing machine. Fig 2.1 c) & d) show the fatigue specimen of straight and helical tube after failure.

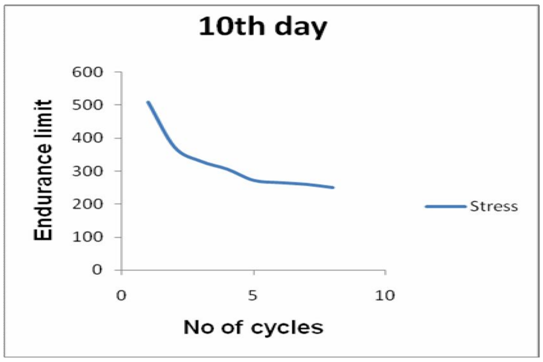
3. Result and Discussion:

3.1 Endurance limit for stainless steel straight tube receiver:

(a)



(b)



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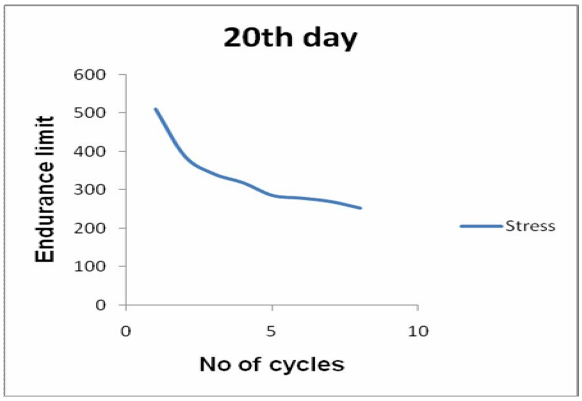

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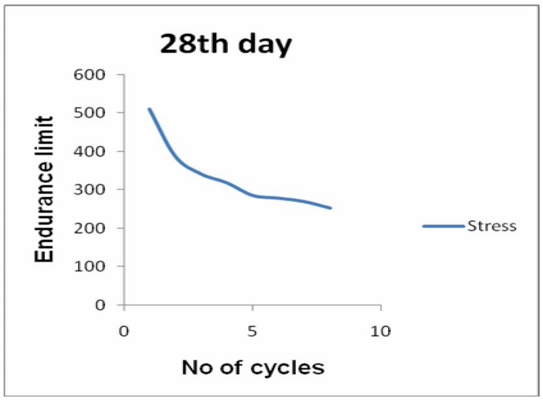
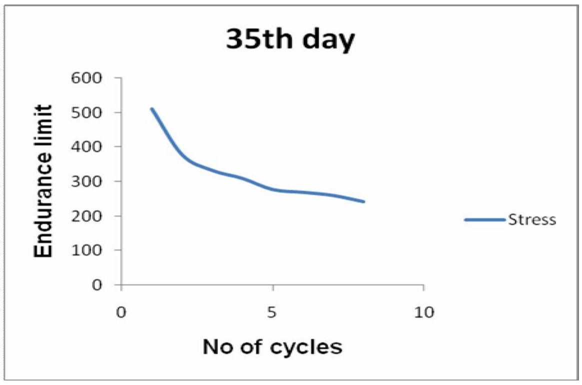
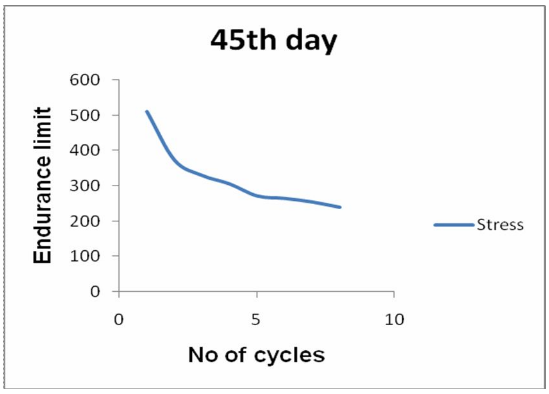
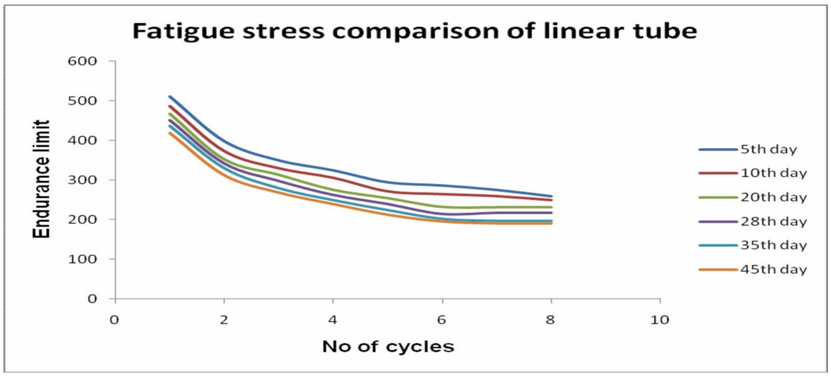


(e)



(f)





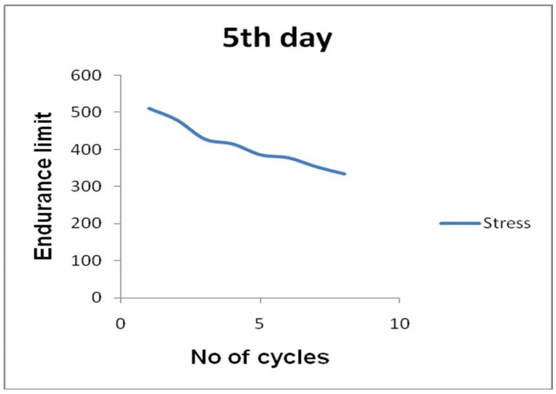
(g)

Fig 3.1: Endurance limit variation of SS straight tube for various days of heating (a) 5th day (b) 10th day (c) 20th day (d) 28th day (e) 35th day (f) 45th day (g) EL comparison

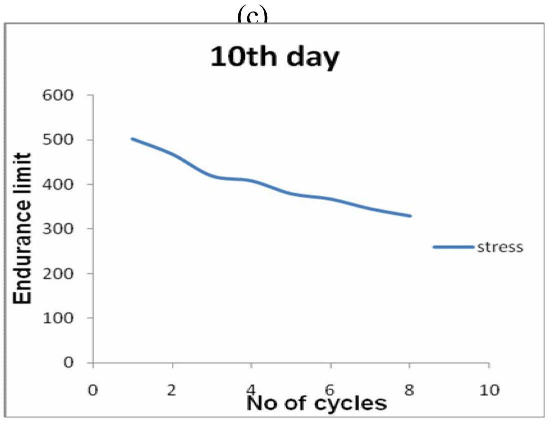
The endurance limit is the stress value below which the specimen can continue to operate without failure for 106 cycles. In fig 3.1 a) to g) the x axis unit represents 125000 cycles, therefore the number of cycles corresponding to 8 is 106 which is selected as EL for present study. The endurance limit gets changed from 260 MPa to 190 MPa as the straight tube continues to operate under high temperature asymmetrical heat flux condition. At the beginning of operation the reduction in EL is at higher rate compared to the later stages. From fig 3.1 g) it is clear that the EL is almost same for 35th and 45th days of exposure. The slope is steeper at the low cycle of operation and shallower at high cycles.

3.2 Endurance limit for stainless steel helical tube receiver:

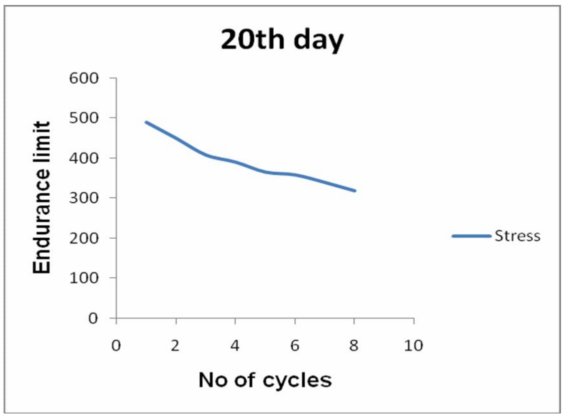
(a) (b)

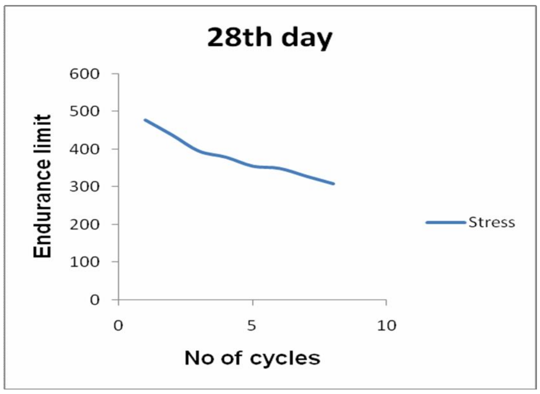


(c)

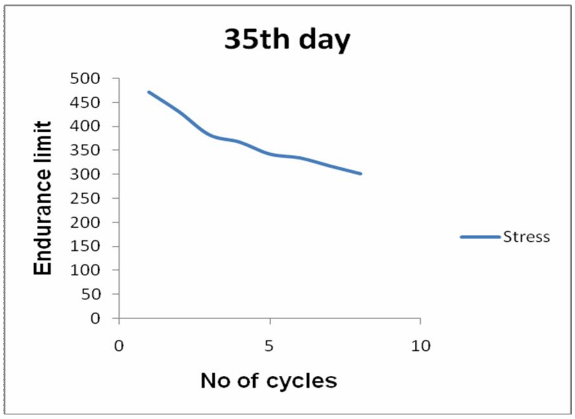


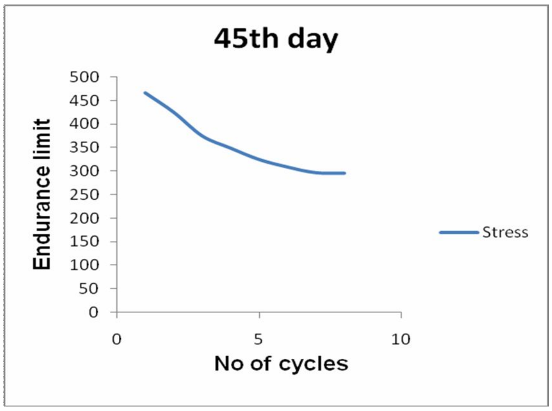
(c) (e)

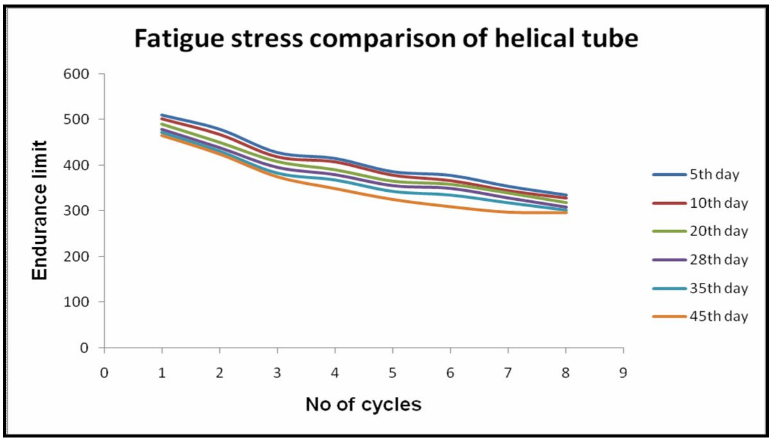




(e) (f)







(g)

Fig 3.2: Endurance limit variation of SS helical coil tube for various days of heating (a) 5th day (b) 10th day (c) 20th day (d) 28th day (e) 35th day (f) 45th day (g) EL comparison

The EL of helical coiled receiver tube is presented in the fig 3.2 a) to g) and then it is found that the endurance limit gets changed from 335 to 296 MPa for the day exposure period variation of 5 to 45. The slope is steeper till 375000 cycles, and then becomes shallower at higher cycles of operation. Almost all the days of exposure at higher cycles the EL is very near to each other and the variation if found to be just 39 MPa instead of 44 MPa at low cycle operation.

3.3 Endurance limit comparison for stainless steel straight and helical tube receiver:

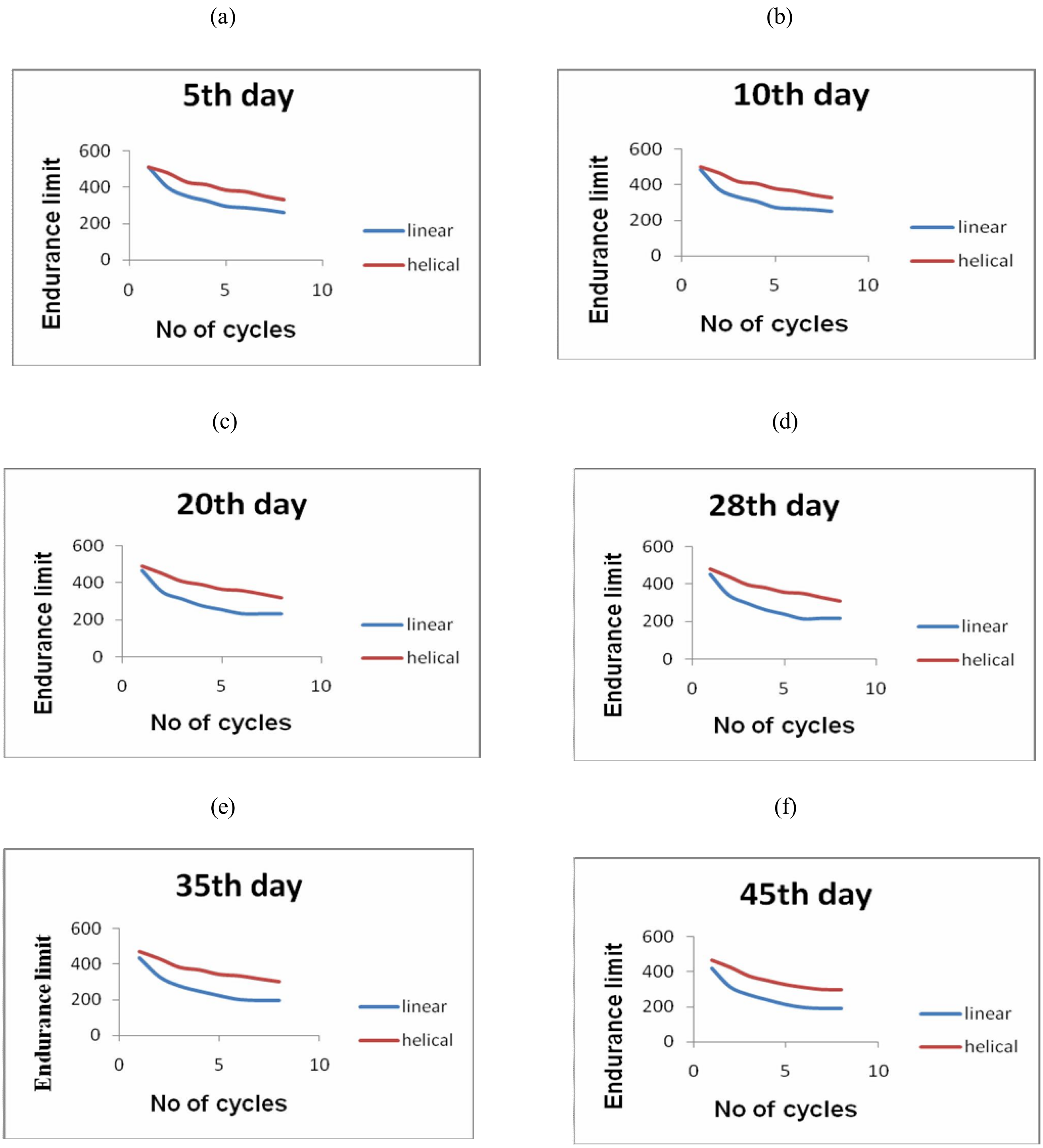


Fig 3.2: Endurance limit variation of SS helical coil tube for various days of heating (a) 5th day (b) 10th day (c) 20th day (d) 28th day (e) 35th day (f) 45th day

From fig 3.2 a) to 3.2 f) it is found that the curves are diverging in nature as day increases, which means the endurance limit of linear tube decreases at the faster rate compared to the helical coiled tube. At the end of 45th day the maximum difference is found for 10^6 cycles. The 28th day is included in the analysis since in our previous work on circumferential strain we found that the permanent deformation only beyond 28 days of exposure to heat flux.

4. Conclusion:

The fatigue behavior of stainless steel tube for both proposed helical coiled tube and conventional straight tube receiver geometry has been studied using thermal oil under asymmetrical heat flux condition for 45 days. It is found that the fatigue life and endurance limit is much higher for helical tube compared to the straight tube receiver, and this is due to the uniformity in circumferential temperature distribution of helical tube compared with the straight tube.

Table 1: Straight tube EL

5^{th} day	10^{th} day	20^{th} day	28^{th} day	35^{th} day	45^{th} day
260	250	231	218	198	190

Table 2: Helical tube EL

5^{th} day	10^{th} day	20^{th} day	28^{th} day	35^{th} day	45^{th} day
335	329	318	308	302	296

Comparison of strain is made between linear and helical tube in table 1 and 2. For 5^{th} day the difference is around 75 MPa and increases up to 106 MPa at the end of 45 days of operation. It is very clear that not only EL is small for linear tube also whose reduction is at faster rate compared to the helical tube. The helical tube is found to be the best geometry in the fatigue behavior compared to linear.

Nomenclature:

TMF ThermoMechanical Fatigue
ODS Oxide Dispersion Strengthened
EL Endurance Limit.
FSI Fluid structure interaction

References

1. Jianghui Mao, Carlos C. Engler-Pinto Jr., Tie Li, Jerry Hsieh, Xuming Su, Effect of Constitutive Model on Thermomechanical Fatigue Life Prediction, Procedia Engineering 133 (2015) 655 – 668.
2. Abderrazak Daoud, Jean-Bernard Vog, Eric Charkaluk, Lin Zhang, Jean-Claude Biasci, Effect of temperature on the low cycle fatigue behavior of Glidcop Al-15, Procedia Engineering 2 (2010) 1487 – 1495.
3. O. Flores, C. Marugán-Cruz, D. Santana, M. García-Villalba, Thermal stresses analysis of a circular tube in a central receiver, Energy Procedia 49 (2014) 354 – 362.
4. Myung Jo Jhung, Assessment of Thermal Fatigue In Mixing Tee By Fsi Analysis, Nuclear Engineering And Technology, vol.45 no.1 february 2013.
5. Y. Luo, X. Du, L. Yang, C. Xu, Y. Yang, Study on the allowable flux density for a solar central dual-receiver, International Conference on Concentrating Solar Power and Chemical Energy Systems, Solar PACES 2014.
6. J. Pernpeintner, F. Sutter, Ch. Happich, E. Lüpfert, B. Schiricke, N. Lichtenthäler, J. Thoss, F. Schumacher, Durability testing of parabolic trough receivers–Overheating, thermalcycling, bellow fatigue and antireflex-coating abrasion, Energy Procedia 69(2015) 1540 – 1550.
7. Kai Bauerbach, Michael Vormwald, Jürgen Rudolph, Fatigue Assessment of Thermal Cyclic Loading Conditions based on a Short Crack Approach, Procedia Engineering 2 (2010) 1569–1578.
8. Bao-Cun Du, Ya-Ling He, Zhang-Jing Zheng, Ze-Dong Cheng, Analysis of thermal stress and fatigue fracture for the solar tower molten salt receiver, Applied Thermal Engineering Volume 99, 25 April 2016, Pages 741–750.
9. Fuqiang Wang, Yong Shuai, Yuan Yuan, Bin Liu, Effects of material selection on the thermal stresses of tube receiver under concentrated solar irradiation, Materials & Design, Volume 33, January 2012, Pages 284–291.

10. C. Marugán-Cruz, O. Flores, D. Santana, M. García-Villalba, Heat transfer and thermal stresses in a circular tube with a non-uniform heat flux, International Journal of Heat and Mass Transfer Volume 96, May 2016, Pages 256–266.
11. Simone Sissa, Matteo Giacopini, Roberto Rosi, Low-Cycle Thermal Fatigue and High-Cycle Vibration Fatigue Life Estimation of a Diesel Engine Exhaust Manifold, XVII International Colloquium on Mechanical Fatigue of Metals (ICMFM17).

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