Factors Affecting the Performance of Glass–Metal Seal of Solar Receiver Tubes: A Review

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Abstract:
World is heading towards renewable sources of energy with increase in the population. Solar energy is one of the major renewable energy sources which has tremendous scope because of direct and large solar flux abundance, as well as large open fields to harness the direct sun rays. Generally solar energy is harnessed by PV panels and various kinds of concentrating type receivers. In the concentrating type solar receiver tubes, main cause of failure is leakage at the junction of glass to metal joint (seal) due to high difference in coefficient of thermal expansion of glass tube and steel bellows. These seals are also subjected to high residual stresses and repeated thermal cycling during its operation. For making glass to metal seal, various materials and procedures are under investigation to overcome this failure and increase the life and efficiency of tubes. The effects of various factors on the performance of glass–metal seal of solar receiver tubes were comprehensively reviewed throughout this article.

Keywords: Glass–metal seal; Solar receiver tube; Ceramics; Renewable energy.

Introduction:
Nowadays the world is facing problem of energy crises because of rapid global populace boom, as energy production rate is lagging the energy demand. By 2040 it is expected to see a rise of 40% from now, in the total energy demand. The power production is mainly dependent on conventional fossil based fuels, which are estimated to significantly deplete after 70 years [2]. Today, managing and halting climate changes is a big challenge produced by the overexploitation of conventional resources [3]. Renewable energy is attractive and environmentally friendly option for reducing fossil fuel based power generation. In the field of renewable energy, solar energy is one of the viable and promising aspects for sustainable development. It is expected that solar energy can supply approximately 45% of the world energy demand by 2050 [4]. Presently solar energy is mainly harvested by using photovoltaic (PV) panels and various kinds of solar collectors (i.e., concentrating and non-concentrating type). Concentrating solar collectors receive the solar radiations and convert them into thermal or electric power. Parabolic trough collector (PTC) are proven as the world’s most matured and field tested concentrated solar collector technology which can be used for harnessing of solar energy for large scale. One of the most mature and field tested Concentrating type solar collector technologies for large scale harnessing of solar energy is parabolic trough collector (PTC) [5-8]. In any parabolic trough solar power system, receiver tube is the key component, which typically accounts 30% of the total cost of solar field [6, 7, 9-12]. The parabolic trough receiver tube typically consists of metal tube (absorber) with a solar selective coating and glass
envelops the surrounding of absorber tube to form an annular space between the absorber tube and the glass as shown in Fig. 1.

![Parabolic Trough Receiver Tube](image)

**Figure 1:** Parabolic trough receiver tube [13]

With parabolic trough, solar radiations are concentrated and reflected towards the absorber tube through which heat transfer fluid is flowing. It increases the temperature of heat transfer fluid which finally converts the solar radiation energy into useful thermal energy [6, 7, 9-12]. The purpose of glass tube is to minimize the radiative and convective heat losses. In the space between the metal pipe and glass tube, high pressure vacuum tight environment is maintained with the help of glass-metal transitional elements and metal bellows.

The function of vacuum tight enclosure is to reduce heat losses at high operating temperatures, protect thin film coating of receiver tube from oxidation and accommodate for the difference in thermal expansion in between glass envelope and metal pipe [14-15]. Appropriate distance between glass envelop and absorber tube is kept to avoid large deflections from the hot absorber tube which might cause of breakages in the glass envelope [16]. Dimensional stability at elevated temperatures and chemical inertness at high and low temperatures makes glass as one of the best suitable materials in sealing [17]. Other than PTC tubes, application of glass-metal seals are widely visible in the field of solid oxide fuel cells, electronic component packages, semiconductors, vacuum tubes applications in electronic feed through [18-40].

In the PTC tube, joining of glass and metal is a big challenge for researchers because of differences in physico-chemical properties of glass and metal. Breakage of glass-metal seal is the major issue and adhesive is not an appropriate solution for glass-metal joining due to its lower stability at higher temperatures and low-stress application [13]. Hence failure or degradation of receiver tubes is the biggest cost factor in PTC power plant [43].

Thousands of solar parabolic trough receivers are installed around the globe without the quality control monitoring and standardization [44]. Many factors need to be considered for designing and developing the high quality glass-metal seals if adequate component of lifetime is to be achieved. For the past several years, researchers have been focusing on the designing and development of efficient glass-metal seal by considering the important influencing factors. The objective of current study is to present an exhaustive review of various factors affecting the performance of glass–metal seal of solar receiver tubes.

### 2 Factors affecting the life and integrity of glass metal seal

It is recognized that a wide variety of metals and alloys can be well bond with glass under suitable conditions which led to the development of many useful products and applications [45]. With newer glass ceramic materials, many superior products can be developed along with many advance applications [45-46]. The major challenge is ability to tailor the thermal expansion characteristics of glass and metal to attain a good integrity of glass metal seals over a longer period of time. It make glass-ceramics as an ideal candidate for coating applications and sealing applications where compatible thermal expansions are essentials. In last few years, there has been a dramatic revival of the interest in both glass and glass ceramic to seal metals [45, 47-49].

Substantial work is in progress to enhance the performance characteristics of sealants under the extraordinary working conditions of vacuum, high temperature and thermal cycling at various environmental conditions.

Donald et al. [50] did a comparative study between sealing to multicomponent alloys and pure metals, shows that alloy systems are more likely for deleterious reactions, particularly for Fe or Cr metallic species because of the influence of additional metal species in the reaction one, these helping to promote these reactions. Through careful control of the initial glass composition or processing conditions, deleterious reactions can be minimized.

#### 2.1 Oxide Layer

Direct bonding is not possible in glass to metal seal due to high difference in properties of glass and metal; hence an oxide layer should be developed on the surface of metal which act as a transitional interface [51] from glass properties to metal properties. Therefore the overall properties of the glass bond depend on the properties of the metal oxide layer [52-54]. For topography characterization of surfaces, roughness factor is widely used. Acid etched or passivated titanium surfaces can also enhance the bonding of oxidation layer in sealing [55]. Roughness increased using vegetable oil on stainless steel substrates are also under investigation [56].

Series of alloy were studied by some researchers [57-59] which show that poor mechanical strength is obtained by various metal oxides and mixture of metal oxides that are developed on the surface of most metals and alloys.

AISI 304 type Austenitic stainless steel has FCC structure, which bears high coefficient of thermal expansion while making glass to metal seals. AISI 430 type Ferritic stainless steel have BCC structure which goes under transformation to FCC at around 850°C [51]. This transformation changes the thermal expansion coefficient which may leads to cracks while cooling of glass metal seal. Titanium can be used to obtain fully stabilized ferritic structure. Stable nitrides and carbides can be formed by tiding up carbon and nitrogen with titanium [60]. Hence the stability of ferritic structure can be increased by decreasing the measure of nitrogen and carbon interstitials in the compound.

A study of Mantel [61] indicates that 20% Cr ferritic stainless steel possesses a suitable thermal expansion...
coefficient for sealing to a soft glass. The chromium affects the thermal expansion coefficient of the metal. Thermal treatment under wet hydrogen air leads to a theory of oxide film formation. According to this theory, double oxide layer is formed with thermal treatment. Outer layer is formed with spinel type MnCr$_2$O$_4$ with titanium oxide which dissolves in the glass. Mechanical cohesion is ensured with the inner layer of chromia scale. At the metal-oxide interface, silicon contained in the steel gets segregated and thus decrease the adhesion property of metal oxide consequently metal–glass seal.

Most of the researchers hold that preferable metallic oxide should be FeO or Fe$_3$O$_4$ but never Fe$_2$O$_3$ when Fe is present in the metallic alloy [62]. By peroxidation of metal surface, interfacial chemical bonds are usually formed which ease the transition from ionic/covalent oxide bonding in the glass to metallic bonding. Extensive summaries and technological supports were discussed by Kohl [63] and Pask [64] in their studies.

2.2 Wettability

Wettability reflects contact capacities between two sorts of material. Characterization of wettability of liquid over solid can express in terms of contact angle that the fluid makes on solid surface as shown in Fig. 2.

![Figure 2: Drop size analysis to measure contact angle](image)

If this angle of contact is an acute angle, it shows nonwetting behavior and when this angle of contact is an obtuse angle, solid is wet by the liquid. Generally nonwetting behavior is shown between glass and metal but on introducing metallic oxide film on the surface of metal, wettability becomes very fine.

To achieve strong glass to metal bonding at elevated temperature, high wettability and fusion of glass to metal surface is required. When oxidized glass reacts with metal oxide layer, a strong bond is formed [65, 66]. Following criterion should be fulfilled to achieve better quality of glass metal seal [67]:

- Glass should wet and hold fast to the surface of metal.
- At the glass metal seal interface, ideal oxide layer thickness must exist.
- Metal should not have thermal critical points (allotropic transformations) inside the extended elevated temperatures which will reach in glass to metal seal and least temperature arrived in the service.

- Glass should not re-boil when heated for making the seal nor should be metal give off gases.
- Glass metal sealing must be vacuum tight.

In our previously published study [13] wettability effect of borosilicate glass on different metals was studied and resulted that wettability of borosilicate glass over SS304 is maximum as compared to copper and low carbon steel (LCS 1018) substrates. Due to waviness on the surface of metal, borosilicate glass flowability decreases. Copper oxides are less thermal stable which erode during the sealing process, hence low wettability of glass achieved with copper. Due to no contact angle of glass on LCS 1018, very poor wettability achieved, thus glass detached easily from the surface of LCS 1018 after sealing.

2.3 Materials and thermal expansion coefficient

Glass Metal sealing should have high mechanical strength as well as hermeticity at metal glass bond. For a successful product, extreme performances are expected from the component materials which are produced by utilizing modern technology. Ability to resist weather over a long period of time, can withstand low and high temperature cycles, mechanical loading cycles, etc. are the one part of this success whereas, low product cost, low maintenance cost, low scrap at the time of manufacturing and high reliability in the hands of customer during service are also essential features [68].

Closer the coefficient of thermal expansion (CTE) of metal and glass, lower will be the limit of stresses developed in glass. A craving to utilize stainless steel in glass metal seal led to the development of a family of phosphate glasses [69] who’s CTE (1.78x10^-6° C at 26° to 350° C) nominally matched to 304 stainless steel.

CTE remains constant for a single phase of metal whereas the case is different for glass. Above annealing temperature, CTE of glass increases and becomes unimportant on arrival of softening temperature. If the difference in CTE of glass and metal remains in the range of ±10% [70] from the range of ambient temperature to the glass annealing temperature, almost consistent expansion curves of glass and metal is obtained and the stresses in the glass limits under its tensile strength.

With experimental results and calculation, Chambers et al. [71] concludes that elastically computed stresses are not always conservative. While expressing and predicting the presence of stresses, effect of structural relaxation is extremely important but significantly differs from cursory elastic predictions and capable of producing fractures in glass.

A material combination within a CTE range of 5.0 x 10^-6/K is used to develop matched glass to metal seal in request to guarantee vacuum solidness for the lifetime of the collector. [43].

2.4 Design

In glass to metal seals, there are inevitable residual thermal stresses generated, not only by the difference in CTE
between glass and metal but also due to sealing geometry [72-73]. These residual stresses produce negative effect to the seal strength. For designing of glass-metal seal, generally three approaches are pursued which are, compressive sealing, bonded sealing and compliant bonded sealing [19].

To reduce the end loss in the receivers, short and recompressed bellows are used. Structural parameters were compared among different designs of receiver tube (Himin PTR–2011, Solel UVAC3 and Schott 2008 PTR–70)

**Table 1:** Structural parameters comparison of analyzed receivers [74,75]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Himin PTR-2011</th>
<th>Solel UVAC3</th>
<th>Schott 2008 PTR-70</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4060</td>
<td>4060</td>
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<tr>
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<td>57.5</td>
<td>62.5</td>
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<td>3920</td>
<td>-</td>
<td>-</td>
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<td>57</td>
<td>54.5</td>
<td>59.5</td>
</tr>
</tbody>
</table>

### 3 Factors effecting the efficiency and performance of solar receiver tube

Failure or degradation of glass to metal sealing of heat collecting element (HCE) is considered as the only largest cost factor in 9 parabolic trough solar power plants commissioned in USA. Investigation in parabolic trough solar power technology by [76] concludes that the operating performances for existing power plants with parabolic trough are robust and excellent in commercial power industry. Substantial technology progress has been realized since the last commercial parabolic trough plant was build. Future parabolic trough plants are likely to be more competitive along with economical thermal storage system.

#### 3.1 Thermal Characterization and Stress Concentration

To design and optimize the receiver structure of a parabolic trough for less failure, temperature distribution of solar receiver is also required to identify and analyze [77]. During the formation of glass metal seals, interfacial reactions of glass and metal species may leads to undesirable elements and internal stresses which may affect the behavior and life of seal components. For elevated temperature systems, those reactions which happen under dangerous working states should be considered [22, 50].

Study of overall heat loss, end loss and thermal emittance of the coating are the essentials for evaluating thermal characterization. It helps to indicate the thermal and economic performance of the parabolic trough power plant. Annual thermal loss varies from 10% to 15% of the incident irradiation over the collector [78, 79]. The energy balance in the parabolic trough collector is expressed as follows [80-81]

\[ Q_{\text{coll}} = Q_{\text{abs}} - Q_{\text{loss}} = Q_{\text{abs}} - Q_{\text{g,loss}} - Q_{\text{end,loss}} \]

Where \( Q_{\text{coll}} \) is the total possible collector output, calculated by the increase in enthalpy in heat transfer fluid flowing through receiver; \( Q_{\text{abs}} \) is the absorbed thermal energy; \( Q_{\text{loss}} \) is the overall heat loss power and equal to the sum of \( Q_{\text{g,loss}} \) and \( Q_{\text{end,loss}} \) from the receivers ends.

[16] Examining the overall heat loss (Table 2), end loss and coating thermal emittance of receiver to evaluate its thermal characterization. The heat losses rapidly increase with the increase of absorber temperature. Deviation in temperature is observed while using end coil heater was significantly lower than those without the end coil heaters with absorber temperature of 400ºC. The thermal emittance first decreased and then significantly increases with the increase in absorber temperature. A higher emittance at a lower temperature may be caused by the ratio of the end heat loss in the total heat loss being too high.

**Table 2:** Comparison of heat loss for different configurations of receiver at 250ºC [82]

<table>
<thead>
<tr>
<th>Velocity (m/s)</th>
<th>Heat loss (W)</th>
<th>Vacuum shell (W)</th>
<th>Evacuated (W)</th>
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</thead>
<tbody>
<tr>
<td>1.0</td>
<td>456.0</td>
<td>282.5</td>
<td>102.5</td>
</tr>
<tr>
<td>2.0</td>
<td>494.0</td>
<td>290.4</td>
<td>103.2</td>
</tr>
<tr>
<td>3.0</td>
<td>517.0</td>
<td>294.4</td>
<td>103.7</td>
</tr>
<tr>
<td>4.0</td>
<td>533.0</td>
<td>296.9</td>
<td>103.7</td>
</tr>
<tr>
<td>5.0</td>
<td>545.0</td>
<td>298.5</td>
<td>103.8</td>
</tr>
</tbody>
</table>

There is 30-40% failure of the HCEs at Solar Electric Generating System (SEGS) VI-IX over a decade of operation due to thermal stresses in glass metal seals which causes fracture of the glass tube, vacuum loss, and degradation of selective coating in the presence of air [83]. For repairing the tubes, whole plant loop has to be shut down and thus results in the reduction of system efficiency. Sealing joints can crack and tube leakage occurs when stress value surpasses the glass intension. Even in short time it is not a crack but gradually it produces microcrack and with stress function, chronic leakage may occur. On the collision or vibration of these tubes, microcrack expands and spreads rapidly to damage the tubes.

Due to high difference in coefficient of thermal expansion of glass and metal, and high operational temperature difference i.e. metal pipe reaches about 400º C, and the glass tube reaches upto 100º C [84] metal folding bellows are used [5]. Lupfert et al. [85] performs various kinds of thermal tests for characterizing the thermal properties of two available parabolic trough receivers. The main problem for quasiequilibrium test is the lost power determination, for the bench scale test. The main advantage of the presented test is that they include the receiver ends and bellows in the measurement. Investigation concludes that irrespective of the different specifications in emissivity of two products, there were no major differences found in the energy balance at elevated temperature, under a range of uncertainty of several different measuring approaches.
3.2 Coating
Currently available coatings are limiting the operating temperature upto 400ºC above which stability and performance reduces drastically reduce. To increase the operating temperature of solar field from 400ºC to 500ºC, better selective coatings are necessary which possess low thermal emittance and high solar absorptance at 500ºC thus reduce the cost of solar electricity. For high temperatures solar fields, present coatings are neither stable nor giving desirable performance. Future coatings should not only stable in evacuated environment but also in air at the time of vacuum is breached [86]. Some recent designs are planned to reach the working temperature of 600ºC, which will increase the performance by 5 to 10% to attain the market requirement. Such systems are expected to work for 20 to 25 years. Improved coatings have more than 95% absorbance and emittance of 10% at 400ºC [87].

Solar absorber surfaces must have high reflectance (ρ ∼1) at λ≥2μm and low reflectance (ρ ∼0) at wavelengths (λ) ≤2 μm for efficient photothermal conversion. For application in parabolic trough, spectrally selective surface must be thermally stable above the temperature range of 500ºC, ideally in air, bears a greater value then 0.96 for solar absorptance and lower values then 0.07 for thermal emittance at 400ºC [88].

Heat Collection Element (HCE) use an evacuated receiver tube of stainless steel coated with cermet (highly absorbing metal dielectric composites consists of fine metal particles in ceramic matrix or a dielectric), enveloped with Anti reflected coated Pyrex glass and a conventional glass metal seal. Original HCE design used a Mo-Al2O3 cermet solar coating deposited by radiofrequency planar sputtering with good optical properties of α = 0.96 and εM (350ºC) = 0.16 (where εM is the εmeasured at 350ºC) for 350ºC < T <500ºC in the vacuum Lanxner and Elgart [89]. Universal Vacuum Collector (UVAC) employed with a multilayer of Al2O3 based cermet, without the use of Mo, with an improved AR coating with 0.10 emittance and 96% absorptance at 400ºC which is also stable in air and humidity at higher temperatures Mahoney [90]. Further a good literature by Kennedy [86] is available for medium to high temperature absorber coatings, out of which some are durable for above 500ºC operations. Different transition metals, specially formed from refractory metals of group IVA, VA and VIA along with their binary and ternary compounds are suggested for the application in high temperature operations. Cuomo et al. [91], states that Titanium, Hafnium, zirconium metal oxide, boride, nitride, carbide and silicide are few of the materials with highest melting points in nature, where HfC have a melting points of 3316ºC. These materials are very hard, high resistance to wear, oxidation and [92, 93]. For higher photo thermal conversion efficiency then surfaces normally using a homogeneous cermet layer or a graded seal, a double cermet film structure has been developed [94].

Kennedy and Price [8] used Computer aided design software to modeled optically a solar selective coating with α = 0.959 and ε = 0.061 at 400ºC composed a material stable at higher temperatures. Optical properties of the deposited layer are measure, extracted and applied the constants to the model. Calibration of material and thickness and uniformity are verified and also check the stoichiometry and optical properties along with morphology study of individual layer. The thermal and durability of commercial prototypes solar selective coatings (Solol, Schott) and NREL’s prototypes are determined by high temperature exposure in inert gas oven. Results has been analyzed and used to improve advance solar selective coatings.

AR coating is done on both the surfaces of outer glass tube to reduce Fresnel reflective losses from the glass surfaces which maximizes the solar transmittance Lei et.al (2007 -1). Highly efficient selective coating had high solar absorptance of 95% and low thermal emittance, 10% at 400ºC [16].

3.3 Vacuum level and residual gasses
At any existing operational solar plant, the required vacuum conditions in annulus may be compromised by glass breakage, bellow and seal breaking, getter decomposition and hydrogen penetration (Price et al., 2006). Metallic compound getters are used in vacuum annulus to absorb hydrogen and other gases that permeate over time [83]. By NREL, UVAC-3 [75] and Schott PTR70 [74] receivers were tested with indoor steady state equilibrium method in the condition of annulus vacuum. By DLR, similar indoor test stand was established. A research team from Southeast University and Sanle Electronic Group jointly worked together to develop a suitable high temperature vacuum receiver for China’s future parabolic trough projects since early 2000s. When the crucial technologies of high vacuum glass to metal seal is achieved [95] and selective coatings for high performance are developed, a new kind of high temperature receiver specialized for power generation has been developed.

Wang et al. [76] investigated a one dimension non vacuum receiver heat transfer model for four different heat transfer mechanism in non–vacuum annulus. Given model fits accurately to predict receiver’s real heat loss from laboratorial tests and once when vacuum fails, receiver’s heat loss shows remarkable effects on changing the environmental conditions. Performance of selective coating could be roughly evaluated by combining experimental data with one dimension model. To identify the real heat loss in combination with the influence of sunlight, various environmental conditions and at different vacuum, field test with parabolic solar collector and high pressure organic oil (quasi steady state test) was conducted in the parabolic trough solar demonstration project at Sanle Science and Technology park.

Residual gas in the annulus leads to many negative effects such as coating degradation, decrease in system efficiency, environmental sensitivity enhancement. Lie et al. [96] uses ANSYS finite element software and use photoelastic technique to measure the residual stresses distribution in glass metal seals with tubular geometry. Simulation results are agreed with the measured tensile strength of glass to metal joint on material tensile testing machine. Near the glass to metal interface, circumferential residual stresses are compressive whereas axial stresses are tensile on the outer surface and compressive on the inner surface of glass tube. Critical stress concentration occurs
near the glass metal interface zone and hence it should be avoided from heat shocks and nonuniform temperature distributions. Probability of seal fracture can be reduced and seal configuration can be improved by employing rounded end metal ring instead of blunt or think edge ring. Residual stress decreases with the increase in depth of metal embedded into the glass and leads to increase in sealing strength. For glass to metal seal in receiver tube, the optimal depth should be less than 8mm.

Lei et al. [43] suggested that if the difference of CTE between glass and metal is less than 7%, good sealed element is obtained. With the increase in glass tube thickness, value of residual stress drops and seal strength has increase. It is also recommended to have thick end glass tube and length should be more then $x_0$ or $\pi/4$.

4 Modeling and testing methods to analyze the integrity and performance

There are various factors on which the performance and efficiency of solar collectors depends. To analyses these factors through experimental model, a huge amount of money and time is required. Hence by using various software platforms, thermal models are developed easily with a low cost and time. Since 1970s, with the help of thermal models, various studies are conducted to calculate the expected solar field size, to study the collector degradation pattern, various thermal losses and its effect on efficiency and performance of collector can be done. By trailing various fluid flow rates, strategies can be develop to enhance the performances [97].

Many researchers had carried their work in the field of thermal modeling such as Dudley et al. [79], Forristall [80]. A wide study of Padilla et al. [98] and Kalogirou [99] proves and validates the thermal models with the results obtained by experimental setup.

Out of various studies done on one dimensional steady state, an analytical model was presented by Dudley et al. [79] for a parabolic trough solar collector LS-2, SEGS. Results are collected on efficiency and thermal losses of collector by performing several experiments on rotating test platform of AZTRAK, which is situate at Sandia National Laboratories, shows good agreement with the theoretical data. A much more detailed study with Engineering Equation Solver (EES) about one and two dimensional heat transfer model is proposed by Forristall [80] which is applicable for long and short receivers. This EES is capable in calculating thermal performance of parabolic trough solar collector/receiver along with many geometric parameters, various material properties, different kinds of fluid flow and variable operating conditions. For the study of thermal radiation losses at glass envelop and steel absorber, a comprehensive radiative analysis has to be done. Such study for parabolic trough solar receiver/collector was reported by Padilla et al. [98] where they divide the mass of glass envelope and steel absorber in various segments and use energy balance applied through one dimensional numerical heat transfer analysis.

Due to the geometrical position of solar receiver tube and collector, the amount of solar flux received towards the collector side and other side of the receiver tube is different. Similarly the amount of radiation falls over the main receiver tube is much higher and concentrated then the one falls at inactive ends such as steel bellows and glass metal seal. Due to this fact the temperature in the complete fluid line is different at various points. Many researchers studied this variation in temperature and focused their study on those properties which are temperature dependent and produce non-uniformity in the flow line [100-109]. To analyses the fluid flow dynamics and non-uniformity of heat transfer in the application of parabolic trough solar receiver, various software based models were presented. Some of them used numerical methods in computational fluid dynamics (CFD) in three dimensional non-uniform studies [9,100,106-119]. Depending upon the input variables and complexity of three dimensional non-uniform CFD models prepared on particle swarm optimization (PSO) or genetic algorithm (GA) time taken to complete the intelligent optimization varies from few days to week and sometimes up to a few months.

Many researchers worked to increase the heat transfer in receivers and reduce the thermal emission from glass envelops. Reddy et al. [120-125] works in the same domain and suggested many porous inclusions that are inserted at one end of the inner absorber, which ultimately increase the heat transfer in receiver. Infra-Red (IR) reflecting layer is also used to cover the glass tube which helps to suppress the thermal emission. In the study of Grena [123], irradiated half of the glass is covered with IR reflecting layer that reduces the thermal emissions. In the initial stage, optical and thermal simulations, two simplified halve models were derived from liner Fresnel solar collector [124]. Half insulated theory is further investigated numerically for conduction and convection heat loses by Ansary and Zeitoun [125]. They investigate about a receiver tube which is half insulated air filled annulus, which also carried a heat resistant thermal insulation material.

Various studies has been carried out to change the type of flow and producing vortex inside the tube. A three dimensional numerical study has been presented by Cheng et al. [126, 127] in which they coupled heat transfer enhancement and turbulent flow by placing vortex generators at the sides of absorber tube. In other study of one dimensional non uniform or uniform thermal model, two ends were kept at different solar radiation and heat transfer modes. Study concludes the use of thermal model for quick computing, performance analysis on the basis of fluid flow, heat transfer and materials properties.

Software modeling gives a large freedom to researchers in the analytical approach. For evacuated and non-evacuated tubes, efficiency of PTC was predicted by Padilla et al. [98] with the use of analytical heat transfer model. Validations of software models must be verified with the results from experimental setup. In the study of Pope and Schimmel
[128] analytical model was validated with the data obtained from SNL collector test facilities.

5. Conclusions:
Design and manufacturing of glass to metal seal is still a big challenge in front of researchers. Breakage of seal and vacuum breech are the major issues which are affecting the life and performance of solar fields. A limited amount of research in terms of literature, reports, books, patents, industrial investigations etc. is available for various glass-metal seal applications. A detailed review was done to cover all the parameters which affect the integrity of seal, directly or indirectly. Based on those reviews following conclusions are drawn:

- More materials and alloys are required to investigate on micro and Nano level to achieve a better coefficient of thermal expansion of glass and metal and thus reduce the level of residual stresses.
- Various factors affecting the oxide layer properties such as exposure time, surface finish, atmospheric conditions etc. should be carefully observed and tailor to achieve optimum results.
- Wettability factor should be analyzed on micro level and combinations of positive results should also be experimented in a combined manner to attain better results.
- Vast study on thin film coating will also help us to achieve better results with limited resources and setup for receiver tubes and glass envelop.
- Advance getters should be investigated and employed to overcome the residual glasses in annulus. Continuous vacuum with the help of vacuum pumps is also one the possible solution.
- Researchers haven’t got much success in this field; hence many facts need to be addressed in future research to improve the life and performance of glass-metal seal in solar receiver tube. Further R&D improvements will definitely reduce the production cost and time to setup, and investigate the results on a larger scale by additional help of software and computing tools.

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