Analysis of Solar Collector using CuO and Alumina Nano Fluids

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Manuscript Received: Manuscript Accepted:

Abstract

Solar energy is the most abundant of all forms of energy. The renewable energy sources of the sun are quite environmentally friendly and are considered clean. Solar energy as an ecological and environmentally friendly energy has been producing energy for billions of years. Nanofluids are embryonic fluids whose thermal properties are superior to those of conventional fluids. The application of nanofluids consists in achieving the highest possible thermal properties at the lowest possible concentrations thanks to a homogeneous dispersion and a stable suspension of nanoparticles in the host fluids. Nanofluids play an important role in various thermal applications like automotive industry, heat exchangers, solar power generation, etc. Improving the heat transfer in solar collectors is one of the main problems in terms of energy savings, compact design and different operating temperatures. In this article, a comprehensive literature on the thermophysical properties of nanofluids and the application of solar collectors with nanofluids has been compiled and reviewed. The most recent literature shows conventional heat transfer with nanofluids and their specific applications in solar collectors. In this Research CuO and Alumina based nano fluids are used to instead of Water as the working fluid. The research has been carried out for three time periods of 10AM, 1PM and 4PM. When water is replaced by 0.01% of CuO/H2O nano fluid is used this rise in temperature increases to 59% at 10AM, 67% at 1PM and 66% at 4PM, From the results obtained it can be said that increment shown in 0.01% CuO/water nano fluid is greatest, this is due to the better thermal properties of Copper to conduct heat.

Keywords: Nanofluids, Solar energy, Solar systems, Heat transfer enhancement.

I. INTRODUCTION

Ever since the Industrial Revolution took off in the 18th century, fossil fuels have become the first source of thermal energy conversion in the world. Currently, 80% of global energy consumption is based on fossil fuels[1]. Although coal, oil and natural gas have been suitable companions to human development, their disadvantages have become more evident with the increasing energy consumption. Global warming, air pollution, acid rain, and impact on aquatic life by oil spill, which are side effects produced by fossil fuels, are the driving forces that promote the research and implementation of cleaner energy conversion technologies. Moreover, fossil fuels are non-renewable, which means there is a limited amount of these resources available for the near future. For these reasons, the world needs to use energy consciously and generate it from more renewable sources.

Solar thermal systems are becoming a popular alternative to reduce the environmental impacts. These systems require no fossil fuel, and produce little environmental pollution during the manufacture, operation and decommissioning [2]. Another important advantage of this technology compared to other technologies is its availability. The total solar energy flux intercepted by the earth on any particular day is 6.26·1020 Joules per hour. This is equivalent to burning 360 billion tons of oil (toe) per day or 15 Billion tons per hour. However, in 2013, the

BP Statistical Review of World Energy reported worldwide energy consumption of 12.5 Billion tons per year. This means that the earth receives more energy from the Sun in just one hour than the world's population uses in a whole year [3-5]. Solar energy can be converted into electricity in two different ways:

• Photovoltaic systems, which directly converts solar energy into electricity using a PV cell made of a semiconductor material.

• Solar power concentrators, which concentrate energy from the sun to heat a receiver to high temperatures. This heat is transformed first into mechanical energy by turbines, and then into electricity by a generator [6].

A. NANOFLUIDS

Nanotechnology is the kind of technology which provides the materials with size less than 100 nm called nanomaterial. On the basis of the structure and their properties, nanomaterials are divided into four type of category. Carbon based nanomaterial, metal based nanomaterials and composite. Suspend these nanoparticles into any type of conventional fluid like water, oil, ethylene glycol to make nanofluids [7]. The reason why nano size particles are preferred over micro size particles was well explained. With use of nanoparticles over micro particles, there was a much improvement in thermo physical properties. Some important results are:

Table 1: **Difference between nanoparticles and micro particles**

Properties	Nanoparticles	Micro particles
Pump power	High	Low
Stability	Settle	Kinetically stable(long lived in suspension)
Surface/volume ratio	1	1000 times large than micro partial
Conductivity	Low	High
Erosion and clogging	Yes	no

Nanofluids can be used for various applications like air conditioning cooling, automotive, power plant cooling, improving diesel generator efficiency etc. because of the unique properties carried by Nanofluids[8].

B. NANOPARTICLES MATERIALS

Some of the following are the different types of materials having size less than 100 nm used for nanoparticles :-

1) CNT (Carbon nanotubes)
2) Metallic nanoparticles.
3) Non-metallic nanoparticles.
4) Metallic and non metallic oxides.

Most frequently used base fluids with nanoparticles.

1) Water
2) Ethylene glycol based (coolants) etc.

C. NANOFLUIDS IN SOLAR ENERGY

The use of nanofluids for the devices like solar collectors as a working medium is a relatively an innovative idea. In order to improve the physical properties for enhancing direct solar collectors, various studies have to be carried out. As solar power is readily available, researchers are developing the various means to make efficient use of this.

1. The very small size of the particles preferably lets them to pass through pumps without adverse effects.
2. Nanofluids can absorb energy directly--- skipping intermediate heat transfer steps.
3. The nanofluids have high absorption in the solar range and low emittance in the infrared).
4. A more uniform receiver temperature can be attained inside the collector.

5. Enhanced heat transfer via greater convection and thermal conductivity which may enhance the performance of a receiver, and
6. Absorption efficiency may be improved by modifying the nanoparticle size and shape to the application.

For energy applications, two remarkable properties of nanofluids are utilized, one is the thermo-physical properties of nanofluids, enhancing the heat transfer and another is the application of nanofluids in solar collectors. The conventional direct absorption solar collector is a well-established technology, and it has been proposed for a variety of applications. However, the efficiency of these collectors is limited by the absorption properties of the working fluid. This technology has been combined with the emerging nanofluids technologies prepared by liquid-nanoparticle suspension.

II. LITRATURE REVIEW

Ketan Ajay[1]evaluated the effect of nanofluid as a working fluid on parabolic solar collector's overall efficiency through both experimental and CFD analysis. α-Al2O3 nanoparticle of 20 nm average size is used for the preparation of Al2O3-H2O (DI) nanofluid of four different volumetric concentrations of 0.05%, 0.75%, 0.1% and 0.125% respectively. Working fluid is made to flow at three different volume flow rates (30 LPH, 50 LPH and 80 LPH). ANSYS FLUENT 14.5 is used for carrying out CFD simulation, where solar flux is modelled through solar load cell and solar ray tracing. It has been observed that, there is improvement in instantaneous efficiency, thermal efficiency and in overall efficiency, when water is replaced by Al2O3-H2O (DI) nanofluid and also with corresponding increase in the mass flow rate of working fluid. An improvement of about 9.31%, 11.87%, and 13.98% in the collector's overall efficiency is seen, when water is replaced by 0.125% vol. conc. Al2O3-H2O (DI) nanofluid at a flow rates of 30 LPH, 50 LPH and 80 LPH respectively. Also, both experimental and CFD analysis results are in close agreement with a difference of 8%.
Mukesh Kumar et al.[2]presented both experimental and computational fluid dynamics study. Nano fluid possess enhanced thermal conductivity and better heat transfer coefficient as compared tothe base fluid Nano fluid used is 0.01% CuO- H2O (DI). System performance is conducted under mass flow rate of 18Litres/hr. In ANSYS FLUENT 14.5 based computational fluid dynamics tool, the absorber tube is modeled as metalliccopper tube with working fluid flowing in it. Nano fluid is simulated using one-phase modeling techniques, while solarload cell and solar ray tracing are used for modelling the solar fluxes. Solar load model has been used for modeling solar fluxes. S2S radiation model has been used for modeling heat transfer comprising of conduction, convection and radiation. It has been reported from both experimental and CFD analysis that system performance is enhanced by usingNano fluid as working fluid as compared with conventional fluid likes water. Also both experimental and CFDsimulated data gives good result agreement.
Tyagi et al.[3] worked on theoretical and numerical observations to study the effects of different criterion that is nanoparticle size, volume fraction, collector geometry on the efficiency of a low-temperature nanofluid based direct absorption solar collector (DASC).In this paper water based aluminum nanoparticles Al2O3 taken as a working fluid (i.e. composition of water and aluminum nanoparticles). Numerical modelling of DASC was also done by using two dimensional heat transfer analysis. The variation of collector efficiency as a function of the particle volume fraction (0.1% to 5%), particle size, collector geometry was studied experimentally. The variation of collector efficiency as a function of the particle volume fraction (%), where the volume fraction varies from 0.1% to 5% shown in Figure1.The results revealed that by the inclusion of nanoparticles in the working fluid, the efficiency increases remarkably for low values of volume fraction of nanoparticles However, it was found that the inclusion of more nanoparticles is not beneficial because the efficiency remains approximately constant for a volume fraction higher than 2%. Investigations were also carried out regarding the effects of nanoparticles size and collector geometry on the collector efficiency. The results also revealed that the efficiency increases slightly with an increase in the size of nanoparticles. The collector efficiency increases as the collector's height increases and reaches up to the value of 80 %, and with the length factor the efficiency firstly increases with length and then gradually falloffs. It was observed that the rise of collector efficiency to the rise in attenuation of sunlight passing through the collector due to the nanoparticles inclusion leads to the increase of collector efficiency.

Otanicar et al.[4] carried out an experimental and theoretical investigations to study the effects of different nanofluids such as carbon nanotubes, graphite, and silver on the performance of a direct absorption solar collector (DASC). The investigations were carried out to check the variation of collector efficiency as a function of volume fraction for different nanomaterials mentioned above. The DASC data are compared with the conventional collector configuration where the solar energy is absorbed on a black plate surface. It was concluded that by the inclusion of small amounts of nanoparticles leads to the remarkable improvement of the collector efficiency. The efficiency increases up to approximately 0.5% of volume fraction. After a volume fraction of 0.5%, the efficiency begins to level off and even fall slightly with increasing volume fraction. By using graphite nanoparticles of size 30 nm, the performance of DASC over a conventional flat surface absorber was increased up to 3% which was considered to be the maximum enhancement in its performance. In case of silver particles, the main difference in the steady-state efficiency between nanofluids occurred when the size of these particles is between 20 and 40 nm. It was found that when the size of silver nanoparticles reduces from 40 nm to 20 nm efficiency enhancement of 6 % was observed. The collector efficiency as a function of volume fraction was plotted for silver graphite and CNT nanoparticles in figure 3. It was seen that as the size of nanoparticles increases, the collector efficiency decreases.

Taylor et al.[5] carried out theoretical & experimental investigations regarding the applicability of nanofluids in high flux solar collectors and to compare the performance of nanofluid-based concentrating solar thermal system with a conventional system. The results indicated that the usage of a nanofluid as the working fluid in the receiver enhance the efficiency by 10%. It was seen that Collector efficiency enhancement of 5%–10% is possible with ananofluid used as the working fluid in the receiver. It was concluded that using graphite/therminol VP-1 nanofluid for 10–100 MWe power plants, with volume fractions approximately up to 0.001% or less could be advantageous. The authors estimated that in a solar resource like Tucson, Arizona combining solar thermal power tower with a nanofluid receiver with the capacity of 100 MWe operating, could generate $3.5 million more per year. It was observed that, nanofluids are not expected to be appropriate for using as the working fluid for parabolic dish or trough solar thermal systems, but further optimization or cost reductions might increase their range of applicability.

III. GOVERNING EQUATION

The solar load model's ray tracing algorithm can be used to predict the direct illumination energy source that results from incident solar radiation. It takes a beam that is modeled using the sun position vector and illumination parameters, applies it to any or all wall or inlet/outlet boundary zones that you specify, performs a face-by-face shading analysis to determine well-defined shadows on all boundary faces and interior walls, and computes the heat flux on the boundary faces that results from the incident radiation.

ANSYS FLUENT provides two options for computing the solar load: Fair Weather Conditions method and Theoretical Maximum method. Although these methods are similar, there is a key difference. The Fair Weather Conditions method imposes greater attenuation on the solar load which is representative of atmospheric conditions that are fair -but not completely clear.

Which representative of atmospheric conditions that is fair -but not completely clear.

The equation for normal direct irradiation applying the Fair Weather Conditions Method is taken from the ASHRAE Handbook:

$$Edn = \frac{A}{e^{\frac{B}{\sin(\beta)}}} \qquad (1)$$

where A and B are apparent solar irradiation at air mass m=0 and atmospheric extinction coefficient, respectively. These values are based on the earth's surface on a clear day. β is the solar altitude (in degrees) above the horizontal.

The equation for direct normal irradiation that is used for the Theoretical Maximum Method is taken from NREL's Solar Position and Intensity Code (Solpos):

$$Edn = S_{etrn}\, S_{unprime} \qquad (2)$$

Where S_{etm} is the top of the atmosphere direct normal solar irradiance and $S_{unprime}$ is the correction factor used to account for reduction in solar load through the atmosphere.

The calculation for the diffuse load in the solar model is based on the approach suggested in the 2001 ASHRAE Fundamental Handbook (Chapter 20, Fenestration). The equation for diffuse solar irradiation on a vertical surface is given by:

$$Ed = CYEdn \tag{3}$$

where C is a constant whose values are given in Table 7 from Chapter 30 of the 2001 ASHRAE Handbook of Fundamentals, Y is the ratio of sky diffuse radiation on a vertical surface to that on a horizontal surface (calculated as a function of incident angle), and Edn is the direct normal irradiation at the earth's surface on a clear day.The equation for diffuse solar irradiation for surfaces other than vertical surfaces is given by:

$$Ed = CEdn\frac{(1+\cos\epsilon)}{2} \tag{4}$$

Where ϵ is the tilt angle of the surface (in degrees) from the horizontal plane.

The equation for ground reflected solar irradiation on a surface is given by:

$$Er = Edn(C+\sin\beta)\rho_g\frac{(1-\cos\epsilon)}{2} \tag{5}$$

Where ρ_g is the ground reflectivity. The total diffuse irradiation on a given surface will be the sum of Ed and Er when the input for diffuse solar radiation is taken from the solar calculator. Otherwise, if the constant option is selected in the Radiation dialog box, then the total diffuse irradiation will be the same as specified in the dialog box.

IV. BOUNDARY CONDITION

1. The Solar Load model provided by ANSYS FLUENT is used to perform the study, the solar condition of the BHOPAL on 21st of July were considered for the study,
2. Mass Flow rate of 40LPH was given at the inlet of the absorber tube converted in the form of velocity of 0.176m/s
3. The Analysis of the Parabolic Trough Solar Collector is performed for varying Time Period
4. The FLUENT solver is used for present analysis.

V. RESULT AND DESCUSSION

A. Computational Fluid Dynamics for Water as Base Fluid

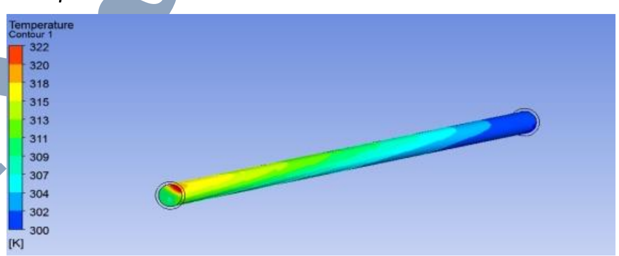

Figure 1: Temperature Contour for base Fluid Of water at 10 Am

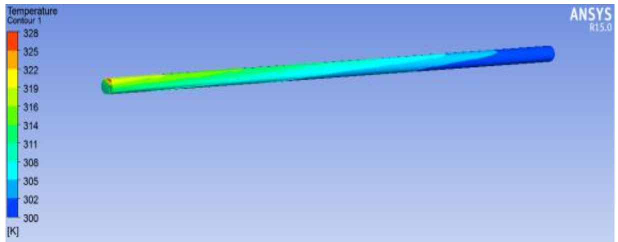

Figure 2: Temperature Contour for base Fluid Of water at 1 Pm

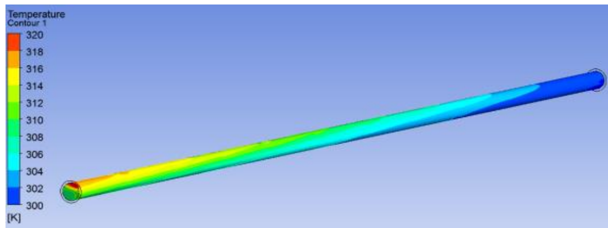

Figure 3: Temperature Contour for base Fluid Of water at 4 Pm

The CFD analysis of Parabolic Trough Solar Collector at various time periods is shown below in the fig 4.4, 4.5, & 4.6. From the results shown below it can be seen that the rise in temperature of the water is maximum at 1 pm when sun is overhead. Since our model was EAST facing which results in the more temperature raise at 10am than 4pm. At 10 Am maximum temperature obtained is 322k where as at 4Pm same is obtained only 320K

B. Parabolic Trough Solar Collector with Copper based Nanofluid

1) CFD Analysis for Parabolic Trough Solar Collector with Copper Based Nanofluid with Volume Concentration Of 0.01%.

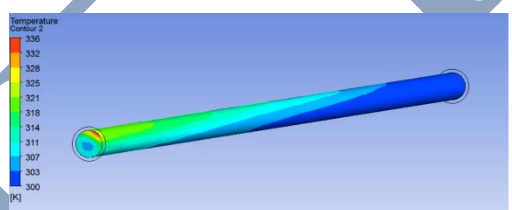

Figure 4: Temperature Contour for 0.01%CuO/H_2O Nanofluid at 10Am

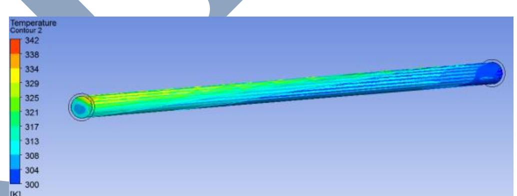

Figure 5: Temperature Contour for 0.01%CuO/H_2O Nanofluid at 1Pm

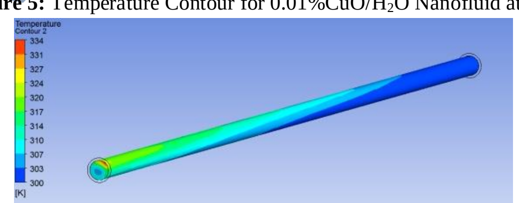

Figure 6: Temperature Contour for 0.01%CuO/H_2O Nanofluid at 4Pm

The result of CFD analysis of the Parabolic Trough Solar Collector With 0.01%CuO/H_2O Nanofluid at various time period is shown above in the figures. The maximum increase in temperature i.e. of 42K is again obtained at 1Pm when the sun is overheard. Followed by 10Am with 36k increase in temperature due to EAST facing geometry.

C. Parabolic Trough Solar Collector with Alumina based Nanofluid

1) CFD Analysis for Parabolic Trough Solar Collector with Alumina Based Nanofluid with Volume Concentration of 0.01%.

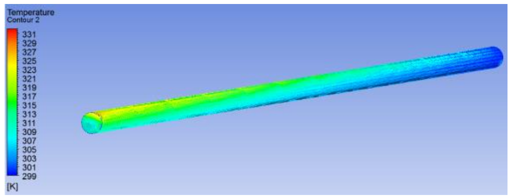

Figure 7: Temperature Contour for 0.01%Al_2O_3/H_2O Nanofluid at 10Am

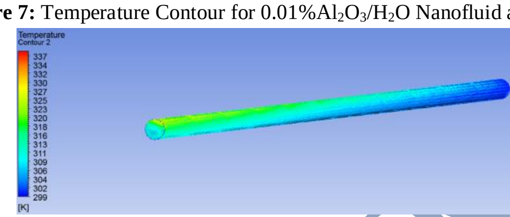

Figure 8: Temperature Contour for 0.01%Al_2O_3/H_2O Nanofluid at 1Pm

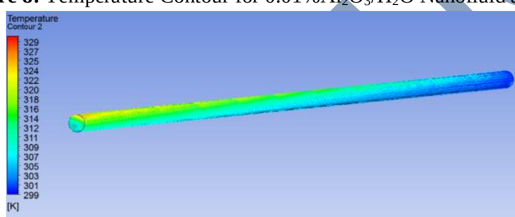

Figure 9: Temperature Contour for 0.01%Al_2O_3/H_2O Nanofluid at 4Pm

The result of CFD analysis of the Parabolic Trough Solar Collector With 0.01%Al_2O_3/H_2O Nanofluid at various time period is shown above in the figures. The maximum increase in temperature i.e. of 37K is obtained at 1Pm when the sun is overheard. Followed by 10Am with 31k increase in temperature due to EAST facing geometry.

Table 2: Results of the CFD analysis

Material	Temper-ature [k] at 10 AM	Temper-ature [k] at 1 PM	Temper ature [k] at 4 PM
Water	322	324	316
0.01% CuO/H_2O	332	338	330
0.01% Al_2O_3/H_2O	328	333	325

A. Results for Water as Working Fluid

Table 3: Results Obtained For the Water as working Fluid from the CFD analysis

Material	Temperature [k] at 10 AM	Temperature [k] at 1 PM	Temperature [k] at 4 PM
Water	322	324	316

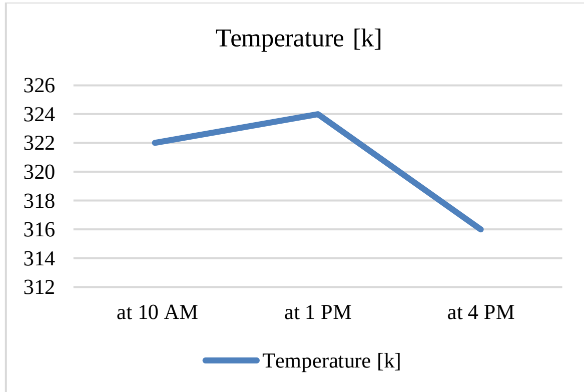

Figure 10: Results Obtained For the Water as working Fluid from the CFD analysis

B. Results for Copper based Nano-fluids

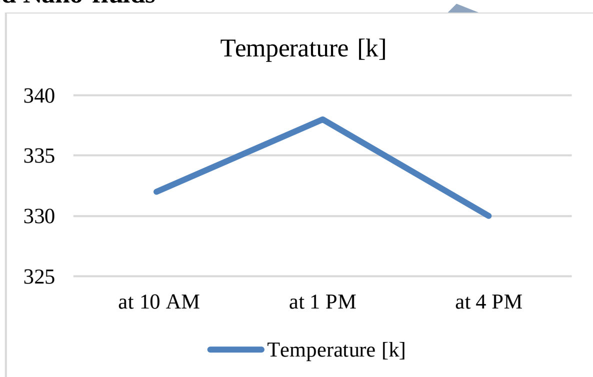

Figure 11: Results Obtained For the CuO as working Fluid from the CFD analysis

Table 4: Results Obtained for Copper Based Nanofluids as working Fluid From the CFD analysis

Material	Temperature [k] at 10 AM	Temperature [k] at 1 PM	Temperature [k] at 4 PM
0.01% CuO/H_2O	332	338	330

C. Results for Alumina based Nanofluid

Table 5: Results Obtained for Alumina Based Nanofluids as working Fluid from the CFD analysis

Material	Temperature [k] at 10 AM	Temperature [k] at 1 PM	Temperature [k] at 4 PM
0.01% Al_2O_3/H_2O	328	333	325

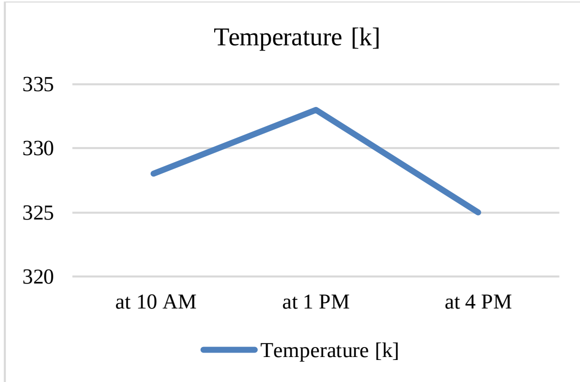

Figure 12: Results Obtained for Alumina Based Nano fluids as working Fluid from the CFD analysis

VI. CONCLUSION

This research work is focused to study the temperature rise of working fluid such as water CuO and alumina in solar parabolic trough collector and analyzed at different temperature condition and observed at 10Am, 1PM and 4PMrespectively. When 0.01% of CuO/H2O nano fluid is used this rise in temperature increases to 59% at 10 AM, 67% at 1PM and 66% at 4PM. Further when 0.01% of Al2O3/H2O nano fluid is used this rise in temperature increases to 38.4% at 10 AM, further it is obtained 29/14% at 1PM and 44% at 4PM The results in the case of CuO based nano fluid were much better than those on the case of water and Alumina based nano fluid. In future work, this research work will be explored to study the nano fluid without surfactant and with surfactant can also be studied along with other nano fluid and their performance can also be analyzed to achieve maximum temperature at minimum temperature rise also be studied.

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