

Modeling of Helium Cooling Tube in Optical Fiber Drawing Tower

Author

Ramesh Behera

Issued

January 2013

Abstract

Convective and radiative heat transfers in annular passage between the cooling tube and optical fiber passing through it at constant speed were investigated during the draw process. Theoretical results show that the cooling rate increases with increase in helium gas flow rate up to an optimum value, followed by a plateau. It is also found that the cooling rate increases with increase in fiber temperature at the inlet of the cooling tube.

Keywords

Optical fiber, Draw Tower, Helium Cooling Tube

Introduction

During the optical fiber draw process from a glass preform, the fiber must cool to a temperature low enough to be compatible with the properties of the coating material. Considering as the initial temperature of the fiber that at the end of neck down, where it reaches its final diameter (commonly taken to be the glass softening point around 1600°C), cooling of the fiber to the required final temperature of around less than 50°C may not be possible by means of natural cooling for high fiber draw speeds unless a tall draw tower is used [1]. However, tall towers are expensive to build and operate. On the other hand, high production rate requires high draw speeds, and as a consequence accelerated fiber cooling becomes a necessary consideration for the drawing process. This can be achieved by means of forced convection using an external gas flow to cool the fiber rapidly.

Generally, the inert helium gas is used instead of inert nitrogen gas in the cooling tube when the fiber draw speed is around 1500-2500 m/min [2]. The thermal conductivity of helium gas is about 6 times more than nitrogen gas and hence the cooling rate is enhanced. It is necessary to optimize the flow rate in given helium cooling tube design as the cost of helium gas is about 2.5 times more than the nitrogen gas. Experiment research can be done to optimize the flow rate, but it is an expensive approach. A theoretical study can be done to decrease the number of experimental work.

This article presents a theoretical study to provide inputs to augmenting fiber cooling rate. The input parameters are considered as the helium gas flow rate and fiber temperature at the cooling tube inlet keeping all other parameters constant.

Theoretical study

All the relevant configurations, as shown in Fig. 1, were chosen to be consistent to helium cooling tubes used in modern draw tower having draw speed at 1500-2500 m/min.

The turbulent axisymmetric flow calculation in the gas medium is considered. The moving optical fiber is considered as solid. The heat transfer transport equations within the optical fiber are coupled with the convective and radiative exchange in the enclosure (i.e. helium gas domain). The temperature dependant physical properties of the glass and gas were considered in the calculation.

The helium cooling tube is made of aluminum and it is cooled by water circulation. The tube inner diameter varies from 6-16mm and length varies from 3-15 meter depending on the draw tower height and draw speed. In the calculation, the dimensions are considered as follows: the fiber diameter is 125 μ m, the cooling tube ID is D mm and the cooling tube length is 600D mm.

Governing equations

The governing equations for mass conservation, momentum, turbulence (i.e. Realizable k-epsilon Model), species transport, energy conservation and radiation (i.e. DO Model) in cylindrical coordinate system were considered in both fiber and inert gas domains [4].

Boundary conditions

The boundary conditions imposed in the glass and gas domains to solve the transport equations numerically in the computational domain are discussed below

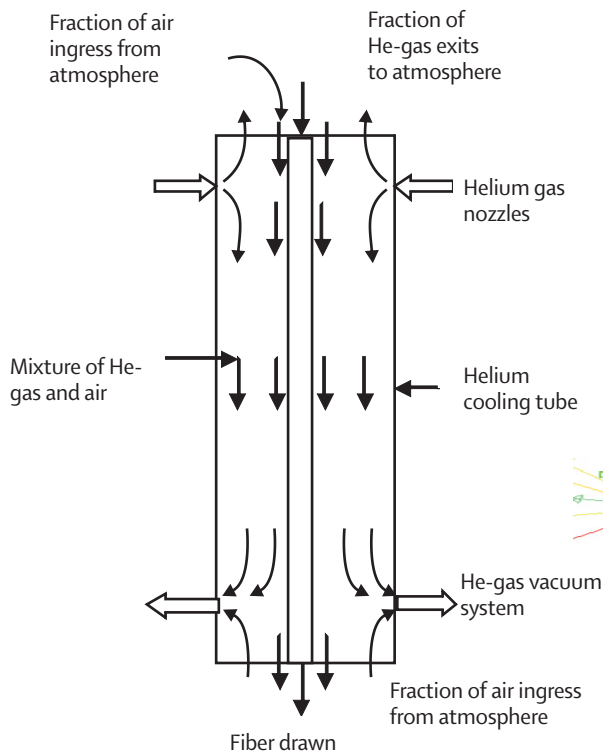


Figure 1: A schematic of the helium cooling tube

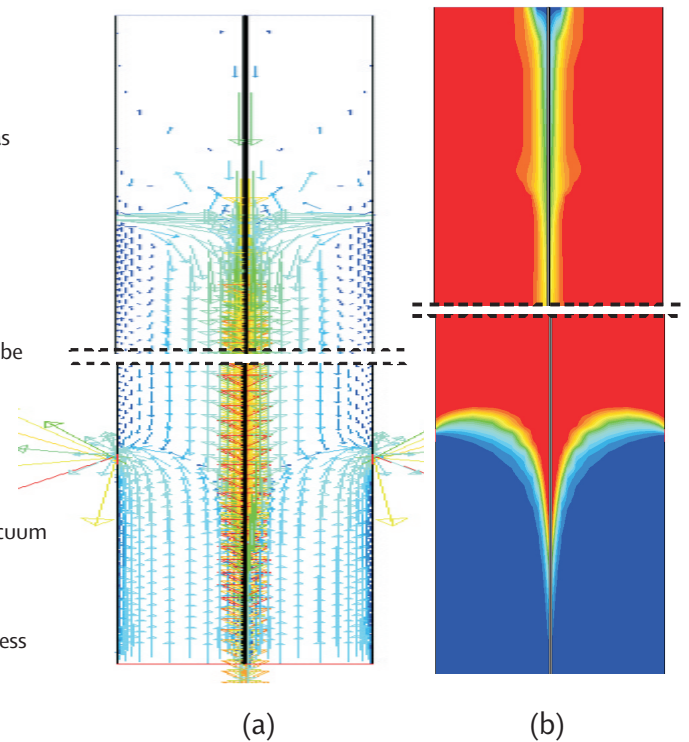


Figure 2: Calculated results are shown in the annular passage: a) velocity vector of gas mixture and b) mass fraction of helium gas. Only zoomed views of top and bottom openings are shown

Fiber Domain

The energy equation associated with radiative heat transfer is solved inside the fiber. The traversing speed is incorporated in the fiber. The fiber entering the cooling tube is imposed with temperature boundary condition. All the fiber surfaces are treated with semi-transparent boundary condition.

Helium Gas Domain

The helium gas, injected sideways near the top opening of the tube, is imposed with the mass flow inlet boundary condition. The vacuum pressure condition is applied sideways near the bottom opening of the tube to collect the gas in a separate recovery system. The top and bottom openings are treated as atmospheric pressure boundary conditions. The boundary shared to both fiber domain and gas domain is treated as a moving coupled wall. The tube wall, cooled by water circulation, is imposed with an appropriate value of heat transfer coefficient.

Numerical scheme

ANSYS FLUENT software was used to solve the governing equations, which is a finite volume method (FVM) based computational fluid dynamics (CFD) code.

The axisymmetric geometry was created using ANSYS Design Modeler. A mapped quad mesh was generated in the geometry using ANSYS Meshing Platform.

The Steady COUPLE pressure-velocity coupling was used as the solution algorithm for the FVM based discretized equations. The 2nd order upwind formulation was selected for the spatial discretization schemes [4].

The iteration process was carried out until the mass and energy balances are achieved in the computational domain.

Results and discussion

The calculated fiber cooling rate is discussed by varying the helium gas flow rate and fiber temperature at the cooling tube inlet. The cooling rate is calculated as fiber temperature drop inside the cooling tube multiplied by fiber draw speed and divided by cooling tube length.

Figure 2 (a) shows that a part of injected helium gas exits from the top opening to behave as a shield to avoid ingress of atmospheric air and simultaneously the gas flows in the downward direction to maximize the convective heat transfer. A mixture of helium gas and air entrainment from the bottom opening exits in the vacuum system. The red and blue colors depict the maximum and minimum velocity magnitudes respectively.

The mass fraction of helium gas is shown in Figure 2(b). The red and blue colors depict the presence of helium gas and atmospheric air respectively.

Figure 3 shows that the cooling rate increases from 797 to 1339 °C/s as the helium gas flow rate increases from 1 to 3 units. However, the cooling rate increases from 1339 to 1348 °C/s as the helium flow rate increases from 3 to 5 units, which is not a significant enhancement. Hence, it is concluded that the optimum operating range of helium flow rate is considered at 3-4 units, keeping other input parameters constant (i.e. fiber temperature at the cooling tube inlet, vacuum condition and draw speed).

The figure 4 shows that the cooling rate increases from 1010 to 3224 °C/s linearly as the fiber temperature at the cooling tube inlet increases from 1 to 3.3 units keeping other input parameters constant (i.e. helium gas flow rate, vacuum condition and draw speed). It is known that the fiber cooling rate depends on two factors: (a) Convective heat transfer coefficient (HTC) and (b) Heat dissipation due to radiation [3]. Both these factors increase as the fiber temperature at cooling tube inlet increases.

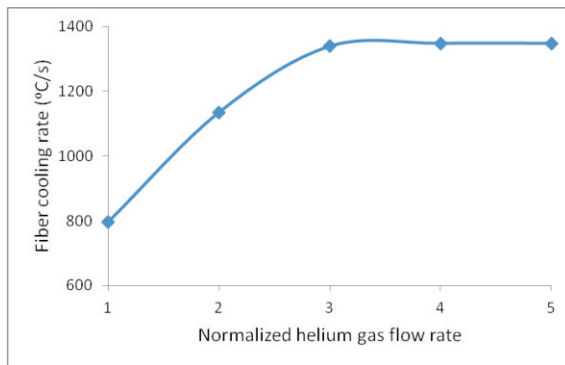


Figure 3: Theoretical results on fiber cooling rate (°C/s) versus normalized helium gas flow rate

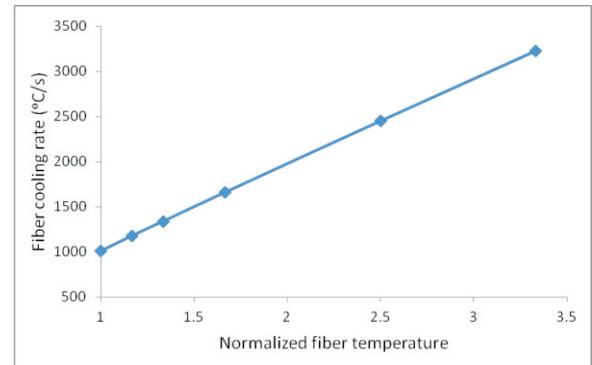


Figure 4: Theoretical results on fiber cooling rate (°C/s) versus normalized fiber temperature at cooling tube inlet

Conclusions

In this study, a theoretical solution of thermal transport in a helium cooling tube was developed. The results demonstrate that the cooling rate increases with increase in the helium gas flow rate up to an optimum value, followed by a plateau. It is also found that cooling rate increases with increase in fiber temperature at the inlet of the cooling tube.

References

- [1] T. Vaskopoulos, C. Polymeropoulos and A. Zebib, "Cooling of optical fiber in aiding and opposing forced gas flow", *Int Jr Heat Mass Transfer* 38, 1933-1944 (1995).
- [2] X. Qian, R. Wang, X. Jiang and Y. Peng, "Improve Stability of Coating at High Draw Speed", *Proceedings of the 55th IWCS*, pp. 490–493, 2006.
- [3] A. A. Stolov and D. A. Simoff, "Fictive Temperature of Larger Diameter Silica Optical Fibers", *Journal of Lightwave Technology*, Vol. 29, No. 7, April 1, 2011.
- [4] *Anslys Fluent v13.0 Theory Guide and Users Manual*, ANSYS Inc