Review on efficient methods for cooling of gas turbines blades on various parameters

Sanjeev Kumar[1], Ruttala Bhavani [2] Minesh Vohra[3]

[1,3]Assistant Professor, School of Mechanical Engineering, Lovely Professional University, Phagwara144402, India

[2] Research Scholar, School of Mechanical Engineering, Lovely Professional University, Phagwara144402, India

Abstract:

Gas turbines are commonly used in propulsion of aircraft, land-based power generation and various industrial applications. Gas turbine working at high-temperature limits. In order to achieve the good performance of the gas turbine, the temperature at the inlet of the turbine should be increase. This high temperature mainly effects the blades of the gas turbine and leads to destroy the turbine blades. To reduce the effect of high temperature, a cooling method is required for gas turbine blades. In this review mainly focused on various cooling techniques like air cooling, steam as cooling medium and coolant paint in air medium were discussed for cooling of the gas turbine blades. Cooling of turbine blades under air as cooling medium and steam as cooling medium are discussed by three different techniques of each like air internal convective cooling, air film cooling and air transpiration cooling under air as cooling medium steam internal convective cooling, steam film cooling and steam transpiration cooling respectively under steam as cooling medium. Also, the parameters like heat transfer, efficiency, temperature reduction on turbine blades, and power output varying due to these coolant methods were discussed. Steam as cooling medium gives best results among the all cooling techniques of turbine blades

Keywords— Transpiration cooling, Convective cooling, holes on turbine blade

1. INTRODUCTION

Gas turbine plays a very important component for producing power. However, gas turbines are used widely in different sources of power generation, the turbine's performance is enhanced by increasing the inlet temperature of a gas turbine, which is the avoidant impact on the gas turbine blades. Thermal performance and power output are enhanced by temperature rise [1][2]. However high temperature leads to turbine blade failure [3]. The high temperature causes thermal corrosion which eventually causes in blade destruction [4]. If the blade reaches the high temperature, there are many possibilities of a turbine blade's goes under thermal failure that ultimately have an impact on the overall failure of turbine. Hence there is a necessity of a cooling system for turbine blades that maintain its temperature and avoid it from failure of blade and turbine. The blade degradation is caused by thermal cracking and thermal blade corrosion due to high temperatures. However, the advanced gas turbine does not withstand high temperature as a classy cooling system is installed to lower the blade temperature. Research has been conducted over the last three decades to examine the methods of cooling in the high-pressure turbine blades. Hence a various method of cooling of turbine blades has been developed. The following figure1 shows different types of cooling methods.

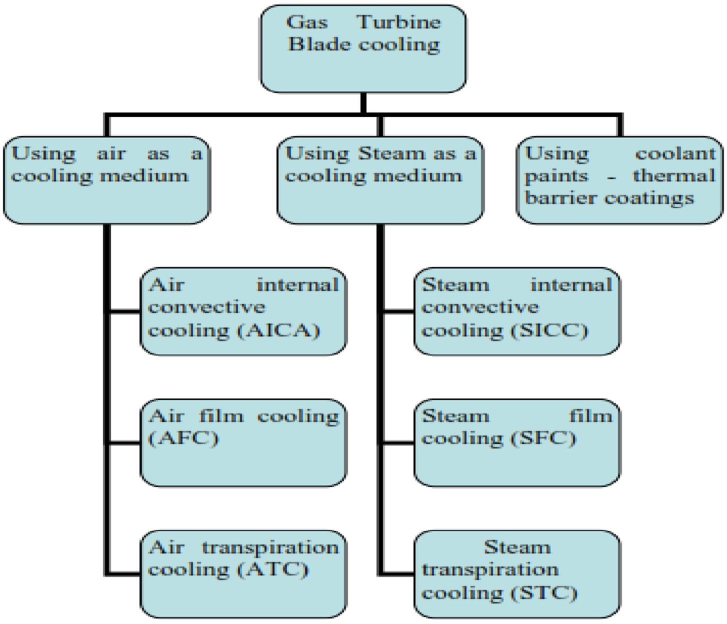


Fig.1 Classification of the blade cooling

1.1 Internal convective cooling

In this cooling the medium goes out of tip by moving the cooling air through internal passages to the turbine blade. Heat is transmitted by conduction through the blade, and then by convection into the air flowing within the blade.

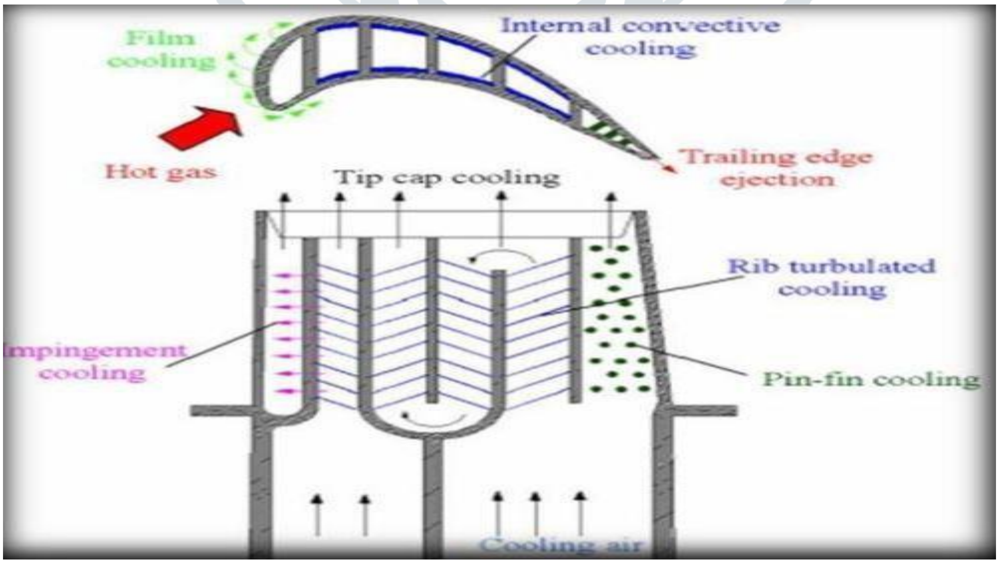


Fig.2 Internal convective cooling [5]

1.2 Film cooling

In recent years, aircraft and power generation gas turbine architects have tried to manage combustor exit and inlet temperatures of stage of high-pressure turbine. By controlling the exit temperature of combustor, the effectiveness improved and fuel consumption reduce. Moreover, the higher temperatures contribute to increased thrust in the aircraft application.

Unfortunately, these higher temperatures have put the safety of the high-pressure turbine components and the sharp edges of the turbine directly at risk.

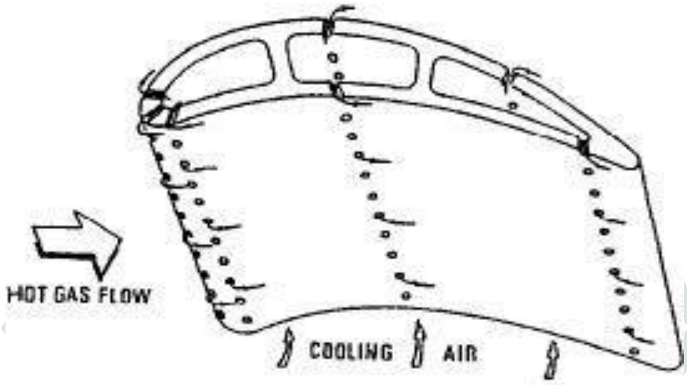


Fig 3: Film cooling [6]

Current turbine stage inlet temperatures reach the melting point of the blade materials. In order to avoid turbine blade failures, film cooling has been integrated for gas turbine engines due to these excessive working temperatures. In the film cooling, the medium is allowed to leave the leading edge of the blade and is enabled to cover the entire blade surface, which minimizing the transfer of heat from the new increasing gas to the blade surface. The cooling is thus due to the combined operation of internal convection and film cooling

1.3 Transpiration cooling

In transpiration cooling, numerous small holes area unit generated on the surfaces of the blades, forming a porous wall through which medium comes out and forms a good thick fluid film on the surface, resulting in reduced heat transfer from hot gasses to blades and cooling is thus formed due to the joint action of internal convection and cooling film.

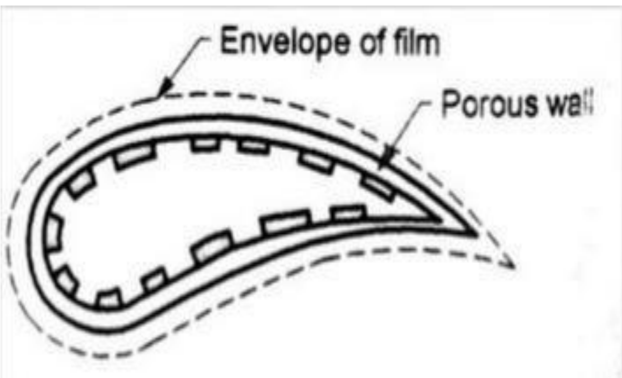


Fig 4: Transpiration cooling **[21]**

2. Past technology on gas turbine cooling methods:

From figure 5 and figure 6 observed that in the early era in 1950 most of the blades were uncooled blades. They could take up to 1000 K and then, leading to higher turbine inlet temperatures, they would have to resort to some kind of cooling technology, irrespective of what material used. At that moment the technology of material was not much developed to solve this issue. So simple cooling technology was used in which a certain amount of cold air indeed passed through the blade. This technology provides a small amount of cooling in the range of 25 °Cto 30 °Cand sufficient to maintain the temperature. After that some more technology was developed that could work under the temperature of 1400K and reduce the rate of heat transfer. After that complex cooling technology were introduced to cool the turbine blades which involve film cooling and then impingement cooling etc., which is taken the turbine temperature into near about 2000K. However modern turbine reaches a temperature of up to 1900 K or 2000 K. However, the less development in material technology has an issue to solve this problem. The projected trend and new material as shown in figure 5 and figure 6.

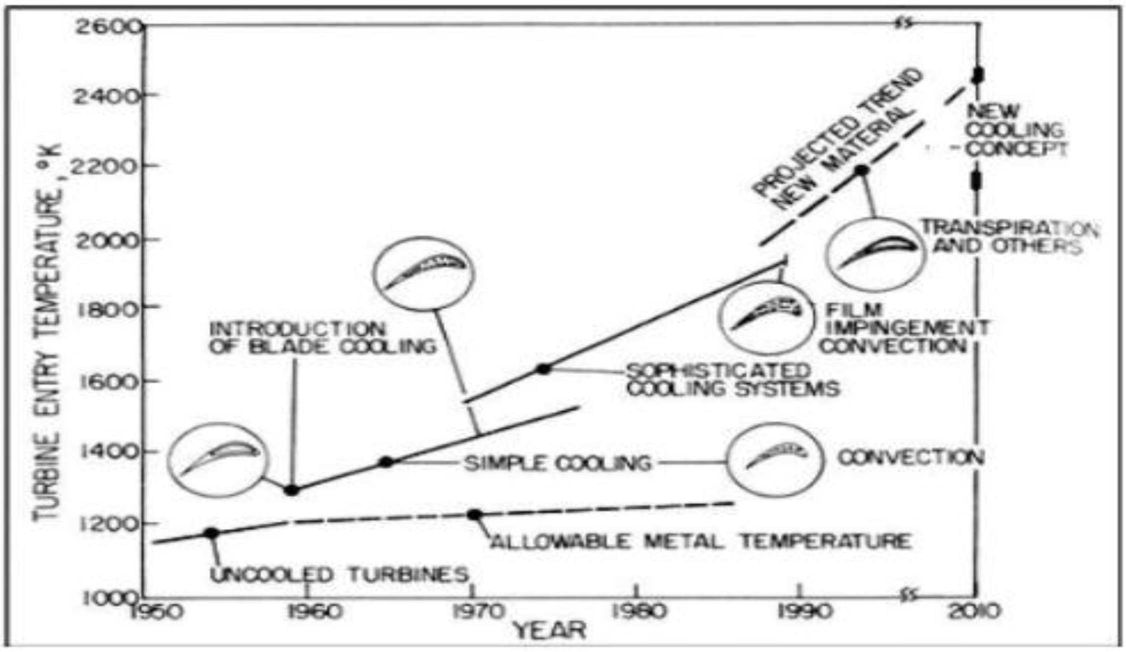
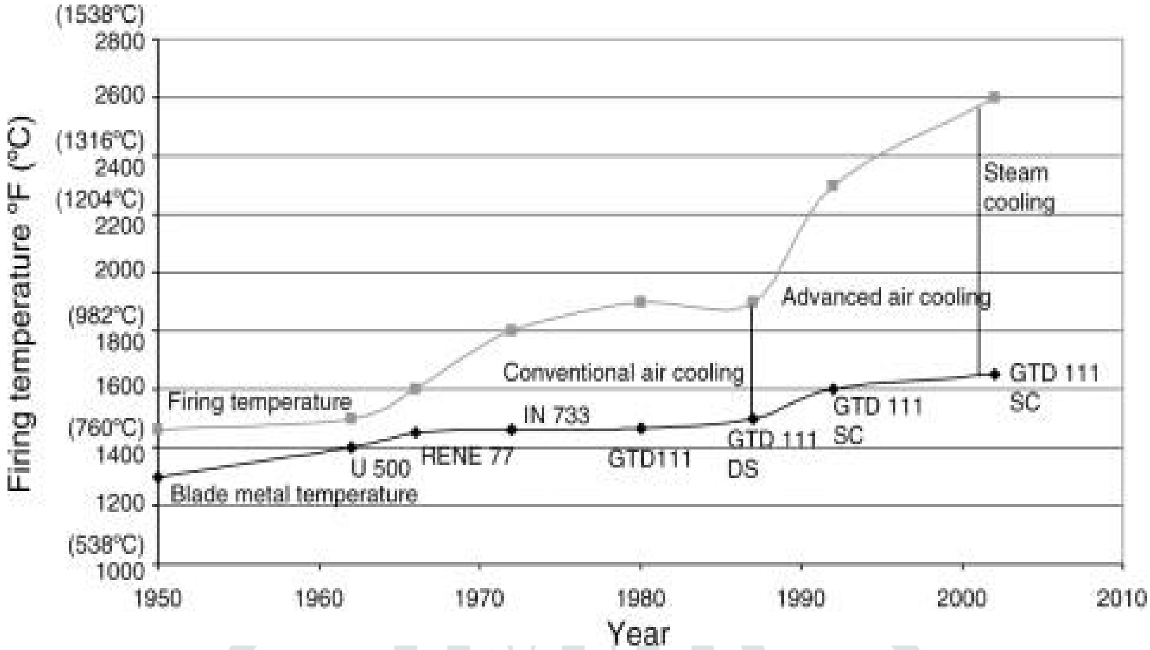


Fig 5: Cooling technology for gas turbine blades [22]

Fig 6: cooling methods [23]



Now we have achieved a temperature range of 2200 K or 2300 K, which does not actually happen, and this is the one of the reasons why cooling technologies have been developed because of material technology is not development yet. Transpiration cooling is the example for these developments.

The new material which was porous material which was facilitated transpiration cooling has not really happened and projected trend not really matured a lot of research are going on and we are not crossing the 2200 K in the year of up to 2010 [22].

Table 1: Summary of the graph [22]

Year	Type of cooling method	Temperature(K)
1950	Uncooled blade	1000 - 1100
1960	Internal 1 or 2 pass cooling	1200 - 1400
1970	Distributed internal convection cooling	1300 - 1500
1980	Film cooling + internal cooling	1600 - 1800
1990	Film + Impingement cooling	1600- 1900

3. Different performance characteristics on the cooling of turbine blades

The different performance characteristics on cooling of turbine blades like heat transfer, reduction of temperature due to the cooling of blades and efficiency of cooling has been discussed.

3.1 Heat Transfer

Mohammad H. et al. used air or steam to examine the heat transfer of gas turbine blades as coolants are studied under various working conditions. [7]. They showed that the result of steam is a better cooling medium than air.

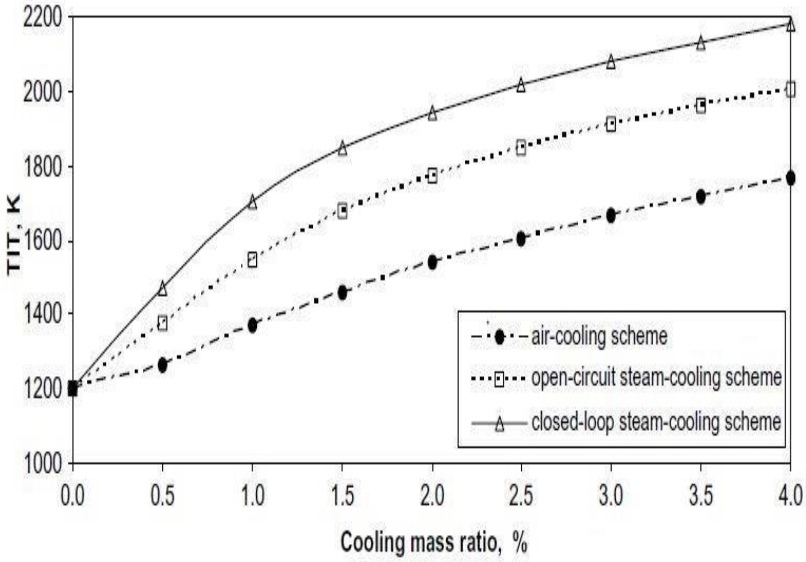
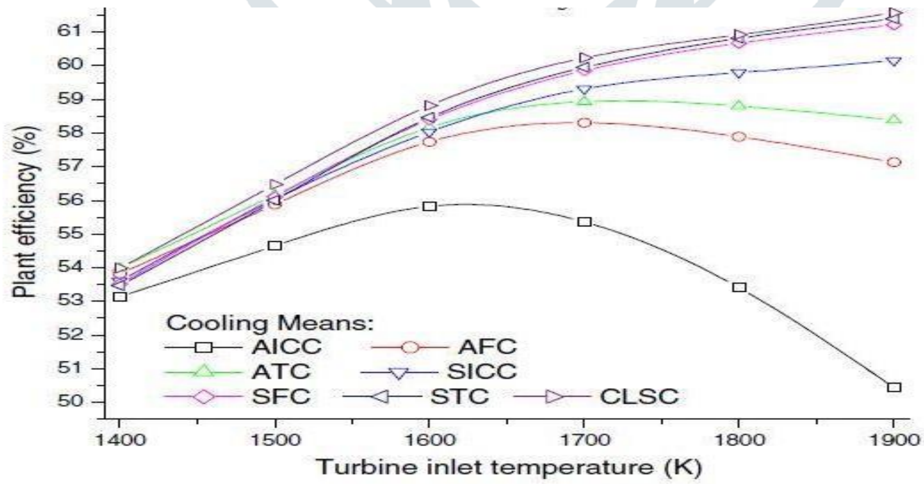


Fig 7. Variation of TIT with cooling mass ratio [7]

Maryam Besharati-Givi et al. [8] Illustrated the relation between the TIT and the amount of cooling air. The blade cooling will enhance the output from 28.8 % to 34.0 % and the net power from 105 MW to 208 MW compared to the simple cycle without cooling. Sanjay et al. This steam cooling provides more specific work and thus gives a higher plant output value of about 60 percent in the combined cycle system[9].

Fig 8. Effect of TIT on plant efficiency for various cooling's [9]

Chao Ma et al. [10] examine an experimental study on the heat transfer properties of steam and airflow



in rectangular channels roughed with the use of an infrared camera [10][11]. Steam has higher performance of heat transfers than air at the same waft state. Xiaojun Shi et al. use of compressed air-cooling technology instead of steam is a useful cooling technology for blades passages and vanes.

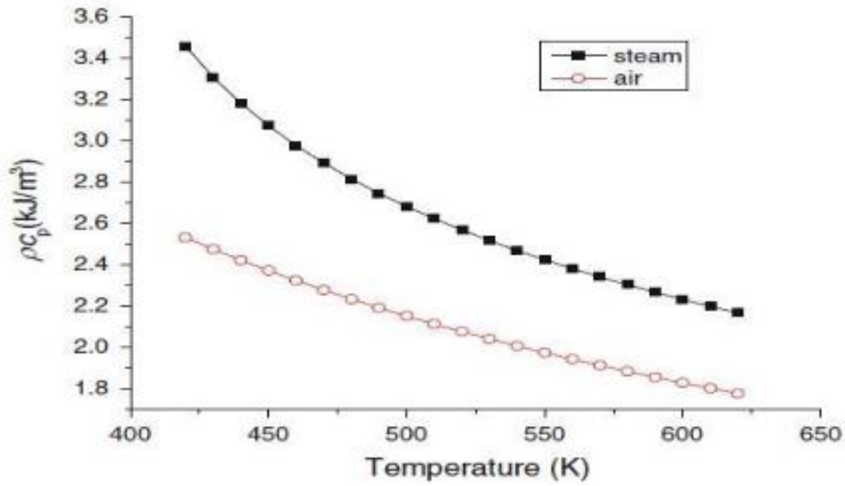


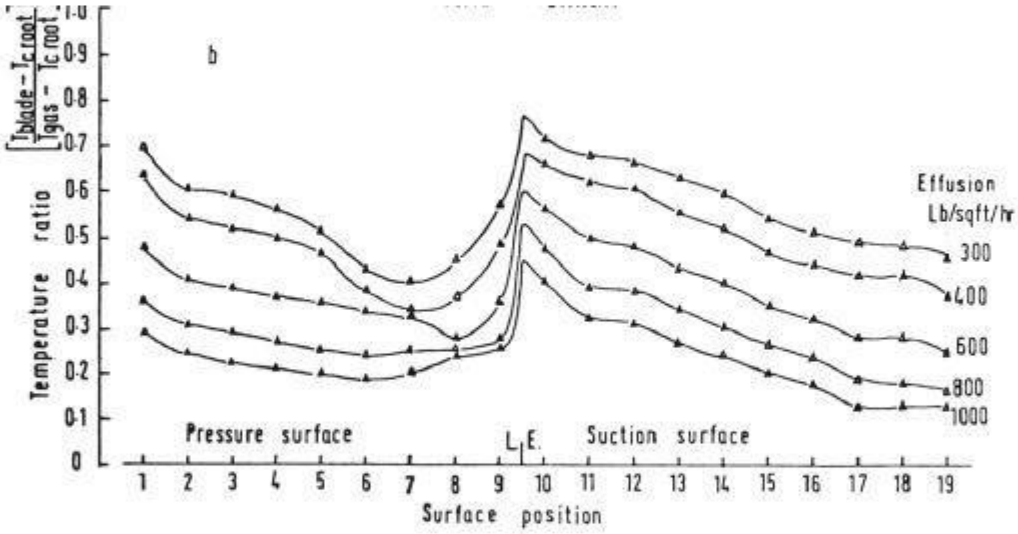
Fig 9. Steam versus Air as a cooling medium **[12]**

In this study, the native characteristics of heat transfer and thus the efficiency of steam flow in large ratio channels with various angular ribs on 2 opposite walls are experimentally investigated [12]. The rib angles are 90 degrees, 60 degrees, 45 degrees, and 30 degrees respectively, steam as the cooling system, the 60 degrees angled ribs have better heat transfer efficiency and are often recommended for cooling design. They also compared air as cooling and steam as the cooling medium and suggested that steam as a cooling medium yields better results than air. Mithilesh et al.[13] in this study, the effect of the operational parameters on gas turbine with convection air film for cooling of blade has been reported. The results indicated that exegetic efficiency will decrease and suddenly rise in power output furthermore decrease with a rise a quantity of bled rise from the compressor. The blade air coolant demand depends on the appropriate temperature of blade material and rotary engine water temperature. Linqi Shui et al. [14] studied provides a computational and experimental study on the transfer of heat and the flow of cooling steam in an extremely rectangular duct with 90 ° ribs and studies the effect of cooling conditions on the increase in heat transfer of steam. The various of parameters like Reynold number, inlet temperature and outlet pressure are varied from 10,000 to 190,000, 300°C to 500°C and 0.5MPa to 6MPa respectively. The results comparative study for heat transfer from steam and air under similar conditions were provided. Results showed that thermal performance is greatly affected by temperature and pressure variation and there is very little impact for varying of Reynold number. Jiangnan et al.[15] Steam has also been used as an internal cooling coolant for gas turbine blades. A lot of work has been done to investigate the heat transfer efficiency of steam in rectangular ribbed channels. The efficiency of steam heat and mass transfer in angular rib channels will be illustrated by the vortex core situation and shape.

3.2 Reduction of temperature due to the cooling of blades

F. J. Bayley et al. [17] experimented with the heat transfer efficiency and temperature variation of Porous gas turbine blades. Measurements of the mass flow rate and thus the temperature of the main gas stream through the cascade were made in this experimental investigation.

Fig 10. Temperature distribution for constant chordwise effusion, Mach number 0-79.[17]



Akira Murata et al. [18] the internal convection cooling is critical because the temperature at the inlet of the turbine is higher to achieve higher thermal efficiency. The combination of spherical dimples, cylindrical protrusions, and crosswise sq is used to improve heat transfer at least one wall of a narrow passage had its ribs added. T. Horbach et al.[19] describes an experimental analysis on the trailing edge film cooling of modern high-pressure turbine blades using coolant ejection through planar slots on a side-cut pressure converter. The elliptic pin fins also have a powerful effect on discharge behavior as well as on film cooling and heat transfer performance. The geometric variations, apart from the elliptic pin fins, have only a slight effect on heat transfer and temperature variations in the gas turbine blades. Sima baheri islami et al. [20] Computational results are provided for a row of fluid injection holes on either side of a hard-hitting gas turbine engine blade. Results show that the most impact of trenching is the reduction of jet lifting away from the surface of the blade so that the bar of abrupt reduction of cooling efficiency once the injection position.

3.3 Efficiency of cooling

R. C. Wilcock et al. examine the effect of turbine blade cooling on gas turbine power cycle performance. A thermodynamic cycle analysis coding system for determining the efficiency of cooled gas turbines has been used to measure the effectiveness of plants with variable combustor outlet temperature.

Table 2 : Improvements in film cooling effectiveness [21]

Hole Shape	%Improvement in η	References
Fan shape	10 – 40	Brittingham et al.[25], Sargison [26], Yu et al [27], Kim[28], Miao et al.[29], Lu et al. [30]
Console	20	Sargison [26]
Conical	15	Falcoz et al. [31]
Sister hole	15 - 23	Dhungel [32]
Compound angle	4 - 10	Waye et al. [33]
Trench shape	15 - 20	Baheri et al.[34]

Additionally, the sensitivity of the cycle efficiency to variance of the parameters specifying the cooling flow levels is examined. Results show that the cycle output of a cooled turbine is mainly concerned with the combustor outlet temperature, the pressure magnitude ratio rp, and even the polytropic performance of turbomachinery, as for uncooled devices. They also discussed the cycle performance variance for a variety of efficiencies and cooling technologies in turbomachinery mechanics. Jong S et al.[21] In this study, variety of cooling hole shapes are evaluated numerically for mistreatment of the fluid dynamics (CFD) machine tool ANSYS-CFX-11.0 with the goal of increasing cooling efficiency below a good pressure gradient main flow. To delineate the results of from that of diffusion, a relentless space magnitude relation is initially assumed and within the next set of analyses, the result of hole exit diffusion is taken into account.

4. Studies on cooling methods

Once gas turbine engine blades are cooled, one does not undergo gradually related changes within the engine's capabilities but incorporates extension over the engine's lifespan. Many authors have made many excellent geometries to cool the turbine blade — making channel ribs, angle holes, impingement, film cooling injection angles, trenched formed holes, vortex cooling, mixing dimples, protrusions and ribs in narrow inner passages, rib angles. Moreover, there is no such material to sustain higher temperatures aside from the turbine needs more inlet temperature to improve output, which is why people depend on methods of cooling. Steam as a cooling medium in these methods yields a good result on the turbine blade cooling.

Conclusions

Thermal performance of gas turbines depends on the gas turbine's inlet temperature. As temperature will increase the efficiency conjointly will increase. As the temperature increases, turbine blades lead to failure. Cooling methods are the simplest Turbine blade cooling approach. The thermal stress is created generally too high a blade temperature so a cooling media should be used properly. The two-cooling media used to measure effectively within which steam provides several satisfactorily cooling results. Trained holes have a reduction of the high temperature and lower the blade temperature. As the number of holes increases the heat transfer rate, it is expected to produce much better results for thirteen holes. It's all about the cooling helps to lower the blade temperature, which is incredibly useful for cooling the turbine power cycle as opposed to other techniques. Cooling helps to reduce the turbine blade temperature by integrating air cooling and steam injection, making it more effective. The injection of steam into the combustion chamber also increases thermal efficiency and the basic work output. Film cooling uses the concept of convection in that a thin layer is created over the surface inside temperature fluid that absorbs heat and cools the product that has a lot of efficiency. It is often the case that film cooling tests entirely different methods, but end wall film cooling is often used to cool the turbine engine tip.

REFERENCES

[1] A. M. Bassily, "Effects of evaporative inlet and aftercooling on the recuperated gas turbine cycle," *Appl. Therm. Eng.*, vol. 21, no. 18, pp. 1875–1890, 2001.

[2] R. C. Wilcock, J. B. Young, and J. H. Horlock, "The effect of turbine blade cooling on the cycle efficiency of gas turbine power cycles," *J. Eng. Gas Turbines Power*, vol. 127, no. 1, pp. 109–120, 2005.

[3] T. J. Carter, "Common failures in gas turbine blades," *Eng. Fail. Anal.*, vol. 12, no. 2, pp. 237–247, 2005.

[4] V. Patarini, N. S. Bornstein, and M. A. DeCrescente, "Hot corrosion of gas turbine components," *J. Eng. Gas Turbines Power*, vol. 101, no. 1, pp. 177–185, 1979.

[5] T Ravi teja and S. K. Chaitanya, "Case study on Turbine Blade Internal Cooling," *Int. J. Eng. Reserach Technol.*, vol. 2, no. 3, pp. 1–5, 2013.

[6] Z. Gao, D. P. Narzary, and J. C. Han, "Film-cooling on a gas turbine blade pressure side or suction side with compoundangle shaped holes," *2007 Proc. ASME/JSME Therm. Eng. Summer Heat Transf. Conf. - HT 2007*, vol. 3, no. January 2009, pp. 569–579, 2007.

[7] M. H. Albeirutty, A. S. Alghamdi, and Y. S. Najjar, "Heat transfer analysis for a multistage gas turbine using different blade-cooling schemes," *Appl. Therm. Eng.*, vol. 24, no. 4, pp. 563–577, 2004.

[8] M. Besharati-givi and X. Li, "POWER2015-49723," pp. 1–9, 2016.

[9] Sanjay, O. Singh, and B. N. Prasad, "Influence of different means of turbine blade cooling on the thermodynamic performance of combined cycle," *Appl. Therm. Eng.*, vol. 28, no. 17–18, pp. 2315–

2326, 2008.

[10] C. Ma, X. Chen, J. Wang, S. Zang, and Y. Ji, "An experimental investigation of heat transfer characteristics for steam cooling and air cooling in a rectangular channel roughened with parallel ribs," *Exp. Therm. Fluid Sci.*, vol. 64, pp. 142–151, 2015.

[11] X. Shi, J. Gao, L. Xu, and F. Li, "Heat transfer performance comparison of steam and air in gas turbine cooling channels with different rib angles," *Heat Mass Transf. und Stoffuebertragung*, vol. 49, no. 11, pp. 1577–1586, 2013.

[12] M. K. Sahu and Sanjay, "Investigation of the effect of air film blade cooling on thermoeconomics of gas turbine based power plant cycle," *Energy*, vol. 115, pp. 1320–1330, 2016.

[13] L. Shui, J. Gao, X. Shi, J. Liu, and L. Xu, "The effect of cooling conditions on convective heat transfer and flow in a steam-cooled ribbed duct," *J. Mech. Sci. Technol.*, vol. 28, no. 1, pp. 331–341, 2014.

[14] J. Zhu, "Gt2014-25324 the Effect of Vortex Core Distribution on Heat Transfer in Steam," pp. 1–8, 2014.

[15] B. A. Jubran and G. Theodoridis, "TURBULENCE INTENSITY EFFECTS ON FILM COOLING AND HEAT TRANSFER FROM COMPOUND ANGLE HOLES WITH PARTICULAR APPLICATION TO GAS," vol. 39, no. 14, pp. 1449–1457, 1998.

[16] F. J. Bayley and A. B. Turner, "The Heat Transfer Performance of Porous Gas Turbine Blades."

[17] A. Murata, S. Nishida, H. Saito, K. Iwamoto, Y. Okita, and C. Nakamata, "Heat transfer enhancement due to combination of dimples, protrusions, and ribs in narrow internal passage of gas turbine blade," *Proc. ASME Turbo Expo*, vol. 5, no. PARTS A AND B, pp. 1173–1182, 2011.

[18] T. Horbach, A. Schulz, and H. J. Bauer, "Trailing edge film cooling of gas turbine airfoils - External cooling performance of various internal pin fin configurations," *Proc. ASME Turbo Expo*, vol. 4, no. PARTS A AND B, pp. 1829–1840, 2010.

[19] S. B. Islami, S. P. A. Tabrizi, B. A. Jubran, and E. Esmaeilzadeh, "Influence of trenched shaped holes on turbine blade leading edge film cooling," *Heat Transf. Eng.*, vol. 31, no. 10, pp. 889–906, 2010.

[20] J. S. Liu *et al.*, "Enhanced film cooling effectiveness with new shaped holes," *Proc. ASME Turbo Expo*, vol. 4, no. PARTS A AND B, pp. 1517–1527, 2010.

[21] www.slideshare.net

[22] www.epfl.ch

[23] http://cerfacs.fr/wp-content

[24] Brittingham, J. and Leylek, J., 2000, "A detailed analysis of film cooling physics: Part IV - Compound angle injection with film cooling holes," Journal of Turbomachinery, 122, pp.133-145.

[25] Sargison, J., "Development of a Novel Film Cooling Hole Geometry," Ph.D., Thesis, University of Oxford,

2001.

[26] Yu, Y., Yen C., Shih, T., Chyu, M., Gogineni, S., “Film Cooling Effectiveness and Heat Transfer Coefficient Distributions around Diffusion Shaped Holes,” Journal of Heat Transfer, 124, pp. 820-827, 2002.

[27] Kim, Y. and Kim, S., “Influence of shaped injection holes on turbine blade leading edge film cooling,” International Journal of Mass and Heat Transfer, 47, pp. 245-256, 2004.

[28] Miao, M., and Ching, H., “Numerical simulation of film cooling concave plate as coolant jet passes through two rows of holes with various orientations of coolant flow,” International Journal of Heat and Mass Transfer, 49, pp. 557-574, 2006.

[29] Lu, Y., Allison, D., Ekkad, S., “Turbine Blade Showerhead Film Cooling: Influence of Hole Angle and Shaping,” International Journal of Heat and Fluid Flow, 28, pp. 922-931, 2007.

[30] Falcoz, C., Weigand, B, Ott, P., ”Experimental investigations on showerhead cooling on a blunt body,” International Journal of Heat and Mass Transfer, 49, pp.1287-1298, 2006.

[31] Dhungel, A., Ekkard, S., “Film Cooling From a Row of Holes Supplemented with Anti Vortex Holes,” M.S. Thesis, Lousiana State University, 2007.

[32] Waye, S. Bogard, D., “High-Resolution Film Cooling Effectiveness Comparison of Axial and Compound Angle Holes on the Suction Side of a Turbine Vane,” Journal of Turbomachinery, 129, pp.202-211, 2007.

[33] Baheri, S., Jubran, B. A., and Alavi Tabrizi, S. P., 2008, “The Effect of Turbulence Intensity on Film Cooling of Gas Turbine Blade from Trenched Shaped Holes,” ASME paper GT2008-50318, 2008.