ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

IARJSET

International Advanced Research Journal in Science, Engineering and Technology

2nd International Conference on Advances in Mechanical Engineering (ICAME-2016)

Amrutvahini College of Engineering, Sangamner

Vol. 3, Special Issue 1, March 2016

Heat transfer enhancement by jet impingement within channel

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Abstract: The paper presented on this study is to represent a scaled up model of jet impingement within channel using single array nozzle pattern. The motivation behind this experiment is that to achieve effective internal cooling and improve the thermal efficiency of gas turbine. The goal of this experiment is to optimize the heat transfer enhancement of the different impingement test sections. Two experimental cases for the analysis using flat test plate and dimple plate surface. The heat transfer rate is increased by making the dimple surfaces on the plate. In the similar way we can study effect of varying aspect ratio and inclination of the plate. For the single array three aspect ratios are 2.5, 3.3 and 4.6 with six reynolds numbers 5000, 6000, 7000, 8000, 9000 and 10000 are investigated. The test is also carried out for inclined test surface with 2.5°inclination.

The exit of jets in three different outflow orientations from impingement channel creates different cross flow effects. However attention is focused on outflow passes out in both directions. Detailed local nusselt number distribution is presented and compared for each case. Span-wise averaged heat transfer coefficients are plotted and compared. Data analysis indicates that for the three aspect ratios, A/R=4.6 produces higher heat transfer coefficients, the varying diameter of dimples produces higher heat transfer coefficient at large reynolds number.

Keywords: Jet impingement, heat transfer, dimples, aspect ratio, reynolds number, nusselt number.

I. INTRODUCTION

Advanced gas turbine engines operate at high temperatures (1200–1500°C) to improve thermal efficiency and power output. As the turbine inlet temperature increases, the heat transferred to the turbine blade also increases. The level and variation in the temperature within the blade material, which cause thermal stresses, must be limited to achieve reasonable durability goals. The operating temperatures are far above the permissible metal temperatures. Therefore, there is a critical need to cool the blades for safe operation.

The blades are cooled with extracted air from the compressor of the engine. Since this extraction incurs a penalty on the thermal efficiency and power output of the engine, it is important to understand and optimize the cooling technology for a given turbine blade geometry under engine operating conditions. Gas turbine cooling technology is complex and varies between engine manufacturers. Fig. 1 shows the common cooling technology with three major internal cooling zones in a turbine blade with strategic film cooling in the leading edge, pressure and suction surfaces, and blade tip region.

The leading edge is cooled by jet impingement with film cooling, the middle portion is cooled by serpentine rib-roughened passages with local film cooling, and the trailing edge is cooled by pin fins with trailing edge injection. In advanced gas turbine blades, rib turbulators are often cast on two opposite walls of internal coolant passages to augment heat transfer. The internal coolant passages are mostly modelled as short, square or rectangular channels with various aspect ratios. The heat transfer augmentation in rectangular coolant passages with rib turbulators primarily depends upon the rib turbulators' geometry, such as rib size, shape, distribution, flowattack- angle, and the flow reynolds number. Rib turbulators disturb only the near-wall flow for heat transfer enhancement.

Therefore, the pressure drop penalty caused by rib turbulators are affordable for the blade internal cooling design. Jet impinging on the inner surfaces of the airfoil through tiny holes is a common, highly efficient cooling technique for first-stage vanes. Impingement cooling is very effective because the cooling air can be delivered to impinge on the hotregion. Jet impingement cooling can be used only in the leading-edge of the rotor blade, due to structure constraints on the rotor blade under high speed rotation and high centrifugalloads.

Several arrangements are possible with cooling jets and different aspects need to be considered before optimizing an efficient heat transfer design. Some of the research studies have focused on the effects of jet-hole size and distribution, cooling channel cross-section and the target surface shape on the heat transfer coefficient distribution. Wide range of parameters affect the heat transfer distribution, like impinging jet, jet size, target surface geometry, spacing of the target surface from the jet orifices, orifice-jet plate configuration, outflow orientation, etc.

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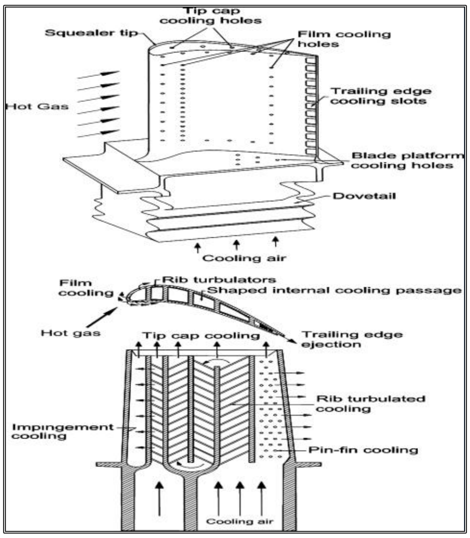

Fig. 1. The schematic of a modern gas turbine blade with commoncooling techniques

II. EXPERIMENTAL DETAILS

A. Experimental Set Up

Fig. 2. Experimental Set Up

It consist of Blower, PVC pipes, BallValve, U-Tube manometer,Connector,ControlPanel,Temperature Indicator,Thermocouple,Heater,Test Section,Impingement plates etc.

B. Experimental Procedure

1) Selecting the plate combination based on the jet pitch, jet arrangement, aspect ratio.
2) Connect all circuit and mounting of experimental set up.
3) Make heater ON for heating heat plate at the base simultaneously make blower ON.
4) Heat is supplied to the bottom side of the plate at constant wattage (120W).
5) There are six thermocouples mounted on the plate,one for inlet condition and two for outlet condition.
6) Select manometer head for particular ball valve position (for six reynolds numbers).
7) According to U tube manometer principle measure manometer head difference.
8) The ambient temperature was measured using a temperature indicator.
9) The reynolds number was calculated using the manometric height.
10) Simultaneously cooling and heating cycle , all temperature are make note down at particular intervals for that particular reynolds number.
11) After getting final steady state make heater off and make cool heat sink by opening butterfly valve fully at atmospheric temperature.
12) Repeat the procedure for different reynolds number and different test plate.

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C. Observation

Ihave found 11127.88 as maximum Reynolds number. So divide this into various stages. By taking different reynolds number such as 5000, 6000,7000,8000,9000,10000 to find out respective height of water column.

TABLE I: REYNOLDS NUMBERS FOR RESPECTIVE HEIGHT OF WATER COLUMN

Re	**H_w (mm)**
5000	17.40
6000	25.05
7000	34.12
8000	44.56
9000	56.40
10000	69.63

III. RESULTS AND DISCUSSION

TABLE IIIII: FOR FLAT PLATE SURFACE Q_{NET}, H_{AVG} AND NU FOR H/D=3.3

S.N	**H/D**	**Re**	**Nu**	**h_{avg}**	**Q_{net}**
1	3.3	5000	104.31	56.75	76.19
2	3.3	6000	114.16	62.11	73.14
3	3.3	7000	129.17	70.27	76.80
4	3.3	8000	145.03	78.90	82.88
5	3.3	9000	187.20	101.85	87.79
6	3.3	10000	194.95	106.06	91.42

TABLE IVVVI: FOR 5 MM DIMPLE SURFACE Q_{NET}, H_{AVG} AND NU FOR H/D=3.3

S.N.	**H/D**	**Re**	**Nu**	**h_{avg}**	**Q_{net}**
1	3.3	5000	124.74	67.86	91.42
2	3.3	6000	143.90	78.29	87.77
3	3.3	7000	171.15	93.12	93.86
4	3.3	8000	180.23	98.05	87.76
5	3.3	9000	232.46	126.49	104.25
6	3.3	10000	245.04	133.32	103.62

TABLE VIIV: FOR 10 MM DIMPLE SURFACE Q_{NET}, H_{AVG} AND NU FOR H/D=3.3

S.N.	**H/D**	**Re**	**Nu**	**h_{avg}**	**Q_{net}**
1	3.3	5000	138.88	75.56	97.52
2	3.3	6000	167.54	91.15	106.05
3	3.3	7000	184.97	100.64	106.66
4	3.3	8000	211.38	115.0	112.14
5	3.3	9000	215.23	117.17	104.25
6	3.3	10000	252.78	137.35	115.81

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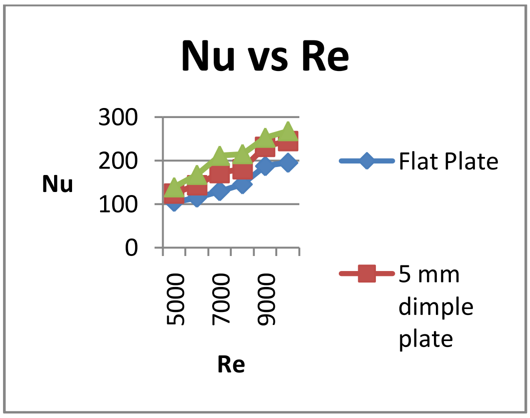

Fig. 3. Averege nussult number distibution for different Reynold's number

Fig. 3. shows the Nusselt number variation for three different plate configurations for different reynolds number and for aspect ratio 3.5. The Nussult number has been found to increase with increase in reynolds number. In general, the percent increase in averege nussult number from flat plate to 5 mm dimple plate is 19.57% and from flat plate to 10 mm dimple plate is 33.13 %.This indicates that 10 mm dimple plate gives higher average Nu as compared to other plates.

IV. CONCLUSION

The above experimental work has disscussed in apprecible depth. The effect of various plate configuration field channel aspect ratios (H/d) and on Nusselt number in a channel cooled by single array of impinging jets (with outflow passing out in both radial directions). It has been observed that Nu is high for higher aspect ratios.In general,the percent increase in avg Nussult number from Flat plate to5 mm dimple plate is 22.67% andfrom Flat plate to 10 mm dimple plateis 35.24 %.This indicates that 10 mm dimple plate gives higher average Nu as compared to other plates. With increase in H/D ratio,Nusselt number is found to increase.It can be inferred that from the above results that invariably (for different feed channel aspect ratio,different plate configuration and outflow orientation etc) average

Nu increases with jet impingement cooling.This implies that jet impingement cooling is effective. This eventually results in increase in thermal efficiency and power density of the gas turbines.The above observations of the experimental work offer valuable information for researcher and designer.

ACKNOWLEDGMENT

It is a matter of great satisfaction and pleasure to present the paper on"Heat transfer enhancement by jet impingement within channel". I express my deep sense of gratitude to Prof.S.A.Ladkat and Dr. S.S. Kore for their valuable guidance discussion and constant encouragement for successful completion of this work.

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