International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

Rapid Cooling System for Jet Propulsion Engine

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Abstract - The project aim is to analyse the methods of rapid cooling systems for jet propulsion engines. The operating temperature of the jet engine is higher than that the turbine blade materials permit. So, we need to design a cooling system to reduce the temperature of the gas at the inlet of the turbine to increase the overall efficiency of the engine. Refrigeration plays a key role in the rapid cooling of the engine, to reduce the heat signatures from the Aircraft and the factors to be considered are mass flow rate, heat capacity, pressure and temperature of the exhaust gas. For Analysing, the Standard design values of gas are taken from the ASHRAE handbook and Steam tables to know the values of pressure at a desired Temperatures and Enthalpies. The heat capacity of exhaust gas is calculated to choose the suitable refrigerant required for effective Rapid cooling.
The main aim of this project is not only rapid cooling of a Jet propulsion engine, but also to know the various properties of materials and various cooling methods employed for the jet engine.

Key Words: HVAC (Heating, ventilation and air conditioning), Jet propulsion, Rapid cooling, Refrigeration.

1.INTRODUCTION

HVAC (Heating, Ventilation, and air conditioning)

HVAC System deals with the concepts of Thermodynamics, Heat transfer, Refrigeration, and Air conditioning, Fluid mechanics, and Energy Conservation. The Prerequisites for HVAC System as shown in figure 1.

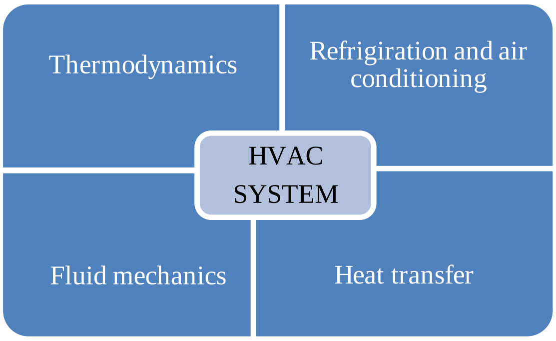

Fig -1: Prerequisites for HVAC System

The three main functions of an HVAC system are interrelated, especially when providing acceptable indoor air quality and thermal comfort. In the HVAC system, we are familiar with the nine parts they are air return, filter, exhaust outlets, ducts, electrical elements, outdoor unit, compressor, coils and blower.

This system controls the temperature, airflow, humidity, and air filtration which results ambient temperature. These HVAC systems are commonly utilized in different segments such as industrial, commercial, residential, and institutional buildings. The main motto of the HVAC system is to fulfil the thermal comfort of occupants by altering and changing the outdoor conditions additionally provide acceptable indoor air quality, the outdoor air is to draw into the buildings and heated or cooled before it is distributed into the occupied spaces, then it is exhausted to the surrounding or reused within in the system.[1]

Jet propulsion engine

The term jet propulsion is nothing but the action produced by a reactor to the ejection of matter. The engine that produces motion as a result of the thrust of a jet of a fluid specifically, an aeroplanes engine that uses atmospheric oxygen(O2) to burn fuel to produce a rearward discharge of heated air and exhaust gases. Jet engines move the aeroplane forward with a great force that is produced by a thrust and causes the aeroplane to fly very fast. All jet engines are also called gas turbines, which work on the same principle. These gas turbines are operating like toy balloons [2].

Working principle of jet propulsion engine

Mainly the jet propulsion engines are working based on the fundamental laws namely, Newton's second law and third law. Newton's second law states that the rate of change of momentum in any direction is directly proportional to the force acting in that direction and inversely proportional to the mass of the body. Newton's third law states that for every action there is an equal and opposite reaction. The working principle of the jet propulsion engine is shown in figure 2.

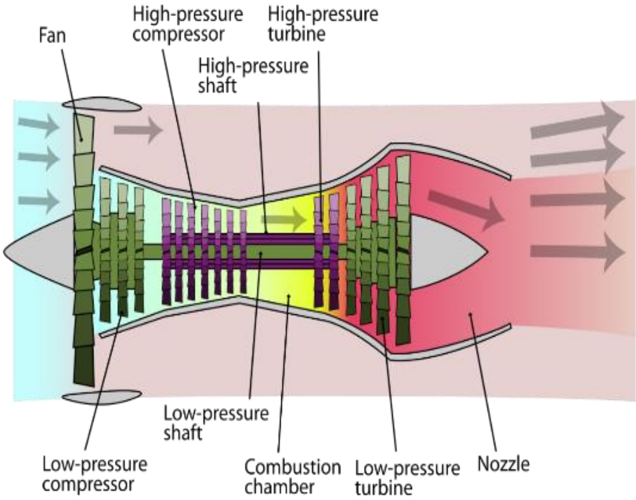

Fig -2: Working Principle of Jet Engine

Refrigeration

If a system is produced and maintained the temperature below than the surrounding atmosphere then the system is called a refrigeration system. For heating and cooling the system in the process of refrigeration, Air conditioners and heat pumps are used. Refrigeration is the process of moving heat and depending on whether it is a heat pump or air conditioner and what mode it is in will depend on where you are moving the heat. The refrigeration process is the elimination of unwanted heat from a selected body, substance, or space and its transfer to another body, substance, or space. Elimination of heat lowers the temperature and may be accomplished by the use of ice, snow, chilled water, or mechanical refrigeration [3].

R32 Background

R32 (difluoromethane / HFC-32), is an HFC refrigerant that has been in utilize for over two decades, most regularly in mixes with other refrigerants. R32 is an eco-friendly refrigerant that has zero ozone depletion potential, a 100-year GWP of 675 and it is slightly flammable. Both R410A and R407A, relatively common current refrigerants, are composed of non-flammable mixtures of refrigerants that include R32. Because R32 has a much lower GWP than these mixtures, it is being evaluated for use as a pure fluid in HVAC&R applications despite past concerns over flammability. Millions of air conditioning units utilizing R32 as a refrigerant have already as of now been sold all through Asia, New Zealand, Australia, and Europe [4].

Advantages of R32

The major advantage of R32 is, it is used in several HVAC&R applications to increases the performance and GWP reductions outlined above represent. R32 has been implemented in air conditioning systems throughout Asia in recent years. Beyond these strengths, there are several pragmatic benefits to the adoption of R32. Manufacturers currently face near-limitless choices of alternative refrigerants by developing customized refrigerant mixtures. However, the implementation of such an approach would be nearly impossible if service technicians and installers are required to acquire and mix dozens of different refrigerant blends. R32 is a pure fluid that is not new to the industry; since it is used as a constituent of many common refrigerants, its availability is far greater than customized and exotic blends. Because it is a pure fluid, R32 has no issues of fractionation, where concentrations of constituent components may vary throughout the system. R32 has been demonstrated as a drop-in replacement for R410A in heat pumping and air conditioning systems. Similar thermophysical properties allow it to operate with compressors designed for R410A with similar operating pressures. Several case studies have been conducted using R32 as a drop-in replacement for R410A, results have varied from essentially equivalent performance 1,2 to claims of up more than 6% improvement in COP3,5 in heat pumping and air conditioning applications.

2. LITERATURE REVIEW

SongXue1 and WingF.Ng: This article Examines an overview of gas turbine blade tip external cooling technologies. And in this paper, he reviewed the cooling performance on flat tip and squealer tip blades from reports are compared and discussed. As a generation conclusion, tip clearance dimension and coolant flow rate are found as the most important factors that significant influence the blade tip thermal performance was well as the over tip leakage (OTL) flow aerodynamics. However, some controversial trends are reported by different researchers, which could be attributed to various reasons. One of the causes of this disagreement between different reports is the lacking of unified parametric definition. Therefore, a more appropriate formula of blowing ratio definition has been proposed for comparison across different studies. The last part of the article is an outlook of the new techniques that are promising for future tip cooling research. As a new trend, the implementation of artificial intelligence techniques, such as genetic algorithm and neural network, have become more popular in tip cooling optimization, and they will bring significantly changes to the future turbine tip cooling development [5].

S.R. Shinen, S. Shri Nidhi said that film cooling in combination with regenerative cooling is presently considered as an efficient method to guarantee safe operation of liquid rocket engines having higher heat flux heat flux densities for long duration. This Reference aims to bring all the research carried out in the field of liquid rocket engine film cooling since 1950. The analytical and numerical procedure followed, experimental facilities and measurements made and major inferences drawn are reviewed in detail, and compared where ever possible. In this Review paper has been done through a discussion of the analyses methodologies and the factors that influence film cooling performance. An effort has also been made to determine the status of the research, pointing out critical gaps, which are still to be explained and addressed by future generations [6].

Ravikant Sahu Eklabya Gupta Deepak Kumar Dewangan This paper briefly reviews some of the work on advanced the liner cooling techniques - specifically laminated porous wall cooling, angled-multirole (effusion) cooling and composite metal matrix liner cooling. The concept definition, heat transfer design procedure and design problems including key materials and fabrication considerations associated with each basic concept will be reviewed. Combustion characteristics and pollutant emissions are studied for different fuels. The influence of droplet diameter on pollutant emissions at all conditions is studied. The fuel and oxidizer are supplied at ambient conditions. The concept of high swirl flows has been adopted to achieve high internal recirculation rates, residence time and increased dilution of the fresh reactants in the primary combustion zone, resulting in flameless combustion mode. Numerical computation has been applied to investigate the temperature field in a gas turbine combustion chamber. The simulation assumed that pressure imbalance conditions of air flow between primary and secondary inlet occur [7].

Benjamin W. Lagow In this Paper Materials selection criteria in gas turbine engine design are reviewed, and several design challenges are introduced where selection of low coefficient of thermal expansion (CTE) materials can help improve engine performance and operability. This is followed by a review of the types of low CTE materials that are suitable for gas turbine engine applications, and discussion of their advantages and disadvantages. The primary limitation of low CTE materials is their maximum use temperature; if higher temperature materials could be developed, this could result in novel turbine system designs for gas turbine engines [8].

Optimized Thermal Systems, Inc. This paper investigates the merits of R32 as an alternative refrigerant with the capability of reducing the global warming impact of refrigerants currently used in the HVAC&R industry. A summary of advantages and disadvantages is provided. Simulation results summarize the theoretical potential of R32 to improve energy efficiency and life cycle climate performance of HVAC&R systems. Overall, R32 is found to be a balanced replacement refrigerant with significantly reduced global warming potential (GWP) when compared with current refrigerants. R32 has the potential to improve system energy efficiency, but some concerns over system design and mild refrigerant flammability remain [9].

3. Kaveri GTRE GTX-35VS

GTRE stands for gas turbine research establishment and it is the manufacturer name. For the analysis of the jet propulsion engine, we considered Kaveri GTRE GTX-35VS, And the specifications are taken as per DRDO publication. And the figure 3 represents the Kaveri GTRE GTX-35VS [10].

The General characteristics of the Kaveri GTRE GTX-35VS is discussed as follows.

- It is afterburning turbofan type of engine.
- The length, diameter and dry weight of the engine is 3,490.0 mm(137.4in), 909.3 mm(35.8in) and 1,236 kg (2,724 lb) respectively.
- It consists of two spool with low and high pressure axial compressor, combustor of annular with a dump diffuser and air blast fuel automiser and also consisting a turbine with one low pressure stage and one high pressure stage.

Fig -3: Kaveri GTRE GT-35VS

Specifications:

- Mass flow rate of air into the jet propulsion engine: Mass flow rate: 78 kg per second
- Turbine entry Temperature is 2600F (14200C;1700K)

T exhaust = 1700 K = 1427 C.

4. METHODOLOGY

In this project, we established or optimized our project based on the below categories as shown in figure 4.

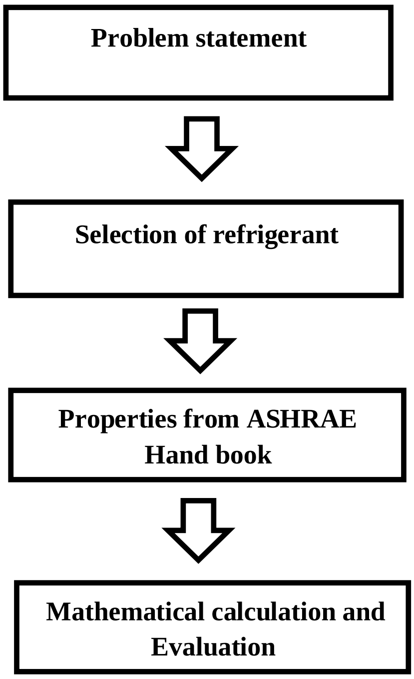

Fig -4: Process flow chart

Problem statement

In any stream basically, the total process is depending on the problem statement is to identify whether the problem is what and where it is, and then we must look for the solution. Then you may proceed to the next steps for solving the problem. In this project, the problem statement is to identify based on the system like in jet engines the main thing is that jet engines need a cooling system. So, without any cooling system, the system may not work efficiently without providing the cooling systems to any engines. And we identified that the problem is cooling which means that the cooling system is to provide for the jet engine in the parts of the gas turbine where we need to cool the system with the help of a rapid cooling system [11].

Selection of Refrigerant

In this project, refrigerant systems play a key role to dissipate or regulating the exhaust temperature which is exhausted from the gas turbine and the nozzle. In our project, we have selected the refrigerant as an R32 because it has a good heat dissipation capacity, less mass flow rate, and it may not harm ozone layers as well as to earth compared with other refrigerants. And mostly we have considered the type of refrigerant used for the system based on the heat capacities. There are five major factors for choosing the refrigerant that must consider in selecting a refrigerant for a particular application is that Performance, Safety, Reliability, Environmental acceptability, Simple economic [12].

Properties from ASHRAE handbook

From the ASHRAE handbook, we have taken the different parameters like enthalpy, density, volume, specific heats, mass flow rate and so on based on the desired pressures and temperatures.

Mathematical calculations and evaluation

We have done a calculation based on the parameters which we have taken from the ASHRAE handbook. For that mathematical calculations and evaluation have taken ideal gas equations and heat dissipation formulas, for calculating how much temperature is dissipating. For that have considered or taken two conditions firstly the actual temperature is noted down without a cooling system and then noted with the cooling system. Then we have calculated the heat dissipation with the cooling system and without a cooling system [13].

5. MATHEMATICAL MODELS AND EVALUATIONS

The suitable properties are taken from ASHRAE Hand book at desired pressures and temperature and have taken the different parameters like enthalpy, mass flow rate and so on which is on particular pressures and temperatures for a R32 refrigerant. shown in table 1. The suitable refrigerant for rapid cooling of jet propulsion engines is chosen based on its heat removal capacity and requires less quantity of refrigerant flow rate, thus less curb weight load on the aircraft. The ideal gas equation can be written as

$$Pv = nRT$$

The pressure (P) is directly proportional to Temperature

- The boiling point of the refrigerant at atmospheric pressure (101.325 KPa) is 200^{0}C
- To ensure lighter engine weight, thin surfaces have to be selected by the design team, and the refrigeration system helps keep the surface safe from thermal deformation.
- In military applications, to reduce the heat signatures of the fighter aircrafts. The refrigeration cycle plays a key role.

Assumptions:

Temperature of the exhaust gases from the jet engine:

Texhaust = 1700 K = 14270C

The mass flow rate of air into the jet propulsion engine:

For Kaveri GTX 35 S, mass flow rate = 78 Kg/s as per DRDO publication

The heat from the engine:

$$Q = m*Cp*\Delta T'$$

Where, Cp - Specific heat of air and fuel mixture,

Cp of air at 1700 K = 1.2293 KJ/KG-K

Cp of Kerosene at 1700 K = 2000 J/Kg-K = 2 KJ/Kg K

Combines CP of air and fuel mixture = (1.22+2)/2 = 1.6 KJ/KG K

Heat, Q = 78*1.6*(1700-293.15) = 175574 KJ/s

Requirement, to reduce heat signature to 50 % or it is estimated that with this much heat, the surface of an engine may deform, thus design engineers specified, maximum heat flow through the surface = 90000 KJ/s

Net heat to be removed by the system = 175571-90000 = 85571 KJ/s

Design a heat sink system/refrigeration system suitable for 85571 KJ/s.

Based on the below considerations we have calculated the parameters

- Choose a refrigerant gas.
- Mass flow rate required for the refrigerant
- Pressure differential for the refrigerant to dissipate heat into the atmosphere.
- Airflow rate required for condensation.

Based on heat capacities, we need to choose a suitable refrigerant.

Table -1: Refrigerants

Refrigerant	Enthalpy Difference	Mass flow rate for 85571 KJ/s	Pressure differential for compression
R12	221.09 KJ/kg	387.09 Kg/s	3.889 Mpa
R22	233.28 KJ/kg	366.81 Kg/s	4.779 Mpa
R32	347.13 KJ/kg	246.5 Kg/s	3.869 Mpa
R410a	245.79 KJ/Kg	348.14 Kg/s	5.309Mpa

From the above table. 1 refrigerants R 32 is considered for the application based on its heat removal capacity and requires less quantity of refrigerant flow rate, thus less curb weight load on the aircraft.

1. R 32 refrigerant, pressurized to get to a temperature of 7500C= 348.15 K
2. Mass flow rate = 348.14 Kg/s
3. Pressure differential = 3.869MPa
4. Air flow rate required for condensation.

Heat Capacity Equation $Q = m*Cp*\Delta T$

85571 = m* 1.006 * (348.15 -293.15)

m = 1546.55 Kg/s

Effect of using the system.

Reduction in exhaust gas temperature.

90000 = 78 * 1.6*(T-293.15)

T - 293.15 = 721.15

T = 1014.3 K = 741.150C.

6. RESULTS AND DISCUSSION

Without an AC system, the temperature of the system would be = 14270^{0}C

The refrigerant used in the system, R 32, Quantity = 348.14 Kg/s

Compression pressure differential = 3.869 MPa

Temperature of the refrigerant at Condenser = 348.15 K = 75^{0}C

Mass flow rate of condenser air = 1546.5 Kg/s

The temperature of exhaust gases with our system =741.150^{0}C.

Here we took the Kaveri GTX 35 S, jet propulsion engine to do the experimental calculations And for this Temperature of the exhaust gases from the jet engine = 1700 K and the Mass flow rate of air into the jet propulsion engine as per DRDO publication 78 Kg/s and by these readings we need to find the heat from the engine by using the formula of Q = m*Cp*ΔT' where Cp is the Specific heat of air and fuel mixture i.e., air and the kerosene and by this the heat from the engine has been found as 175574 KJ/s after getting this much heat we need to reduce heat signature to 50 % or it is estimated that with this much heat, the surface of the engine may deform, thus design engineers specified, maximum heat flow through the surface = 90000 KJ/s then the requirement net heat to be removed is 85571 KJ/s for this we need to design a refrigeration system. And for the refrigeration system, we need to select the refrigerant Based on heat capacities. From all refrigerants R 32 is considered for the application based on its heat removal capacity and requires less quantity of refrigerant flow rate, thus less curb weight load on the aircraft. And for this refrigerant R32, we need to know the mass flow rate by using the net heat to be removed by the engine i.e., Q = m*Cp*ΔT, and the mass flow rate has been found as m = 1546.55 Kg/s. By implementing the refrigeration system by using R 32 refrigerant based on heat capacities. By using this system, the exhaust temperature of the jet propulsion engine dropped 741.150 C from 14270 C.

7. CONCLUSION

By analysing all the refrigerants, we concluded that the R32 refrigerant is a suitable refrigerant for the rapid colling of jet propulsion engines. Here we used R32 refrigerant as a cooling medium depending on its excellent heat dissipation capacity and it requires less quantity of refrigerant flow rate, thus less curb weight load on the aircraft as compared to other refrigerants. The exhaust gas of jet engine is around 1700K, this temperature is greater than that turbine blade material permits, Hence the durability of the turbine blade and overall efficiency decreases. So, to reduce the exhaust temperature we introduced a cooling method of refrigerant system in which R32 is the cooling medium. As a result, the temperature of exhaust gas dropped from 1700K to 1014.5K.

ACKNOWLEDGEMENT

The Paper entitled **"RAPID COOLING SYSTEM FOR JET PROPULSION ENGINE"** is the sum of total efforts of our batch. It is our duty to bring forward each and every one who is directly or indirectly in relation with our project and without who it would not have gained a structure.

We wish to convey our sincere thanks to our internal guide Mr. B. PHANINDRA KUMAR, Assistant professor in Mechanical Engineering, for his profession encouragement in starting this project and academic guidance during the course this project.

We wish to convey our sincere thanks to Dr. B. VIJAYA KUMAR, Head of the Department, Mechanical Engineering for his professional advice, encouragement in starting this project and academic guidance during the course of this project.

We wish to express our candid gratitude to Principal Dr. S. SREENATHA REDDY and management of Guru Nanak Institute of Technology for providing the required facilities to complete our project successfully.

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