Study on the Brine Storage Design During the Engine Running in the Climatic Facility

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Abstract. The engine will consume a large amount of air in the climatic environment facility when the engine is running in the test. The pressure in the chamber may decrease and the temperature in the chamber will change. In order to ensure the continuity and safety of the climatic test, the jet engine make-up air unit (JMAU) will compensate the cold/heat to guarantee the continuous and effective performance of the engine start-up test. Therefore, we should design the brine storage to ensure the supply of the brine.

1. Introduction
The engine is the heat of the airplane, the weather ability of the engine will directly affect the normal flight of the airplane and the normal work of the other systems. Therefore, before the airplane is on service, it is necessary to test the working conditions of the engine based on the full condition aircraft in the various harsh environments. The engine performance, the failures of the engine and the cooperative work of the engine system with other systems are assessed in the test, which will provide favorable basis for the optimal design of the airplane and safe flight.

The engine will consume a large amount of air in the climatic environment facility when the engine is running in the climatic environment facility. In order to ensure the stability of the temperature and the pressure and guarantee the safety, we should compensate the cool/heat. However, whether the cool/heat can be released immediately and continuously will influence the duration of the engine running. Therefore, the investigation on the cooling storage and released will ensure the engine is operated in the facility effectively.

2. The storage system in the climatic facility
As the engine needs to discharge a large amount of high-temperature gas during the start-up, the temperature in the laboratory will rise up. So it is necessary to supply cold air to the laboratory in time. Direct refrigeration cannot meet the cold demand of the laboratory in a short time but it is not easy to control. Therefore, the laboratory adopts indirect refrigeration and stores the cold energy in the coolant storage tank in advance. The secondary refrigeration exchanges heat with the air through the heat exchanger of the JMAU. The cold storage system of the climate laboratory includes cold source of refrigerating unit, secondary refrigeration and brine storage tank.

2.1. Refrigerating unit
The climatic environment laboratory adopts cascade refrigeration, using the 4 high temperature compressor units, the high temperature refrigerant is R507, using the 3 low temperature compressor
units, the low temperature refrigerant is R23, when the test temperature is higher than -25℃, the cooling from the R507 is transferred to the AS-6 to store when the test temperature is lower than -25℃, the cooling is transferred to the AS-6 and dichloromethane to store[1-3].

2.2. Choose of the secondary secondary refrigerant
The climatic environment facility using two secondary refrigerants - the high secondary refrigerant and the low secondary refrigerant[4-7]. The freezing point is lower than -70℃, the freezing point of the high secondary refrigerant is lower than -45℃. According to the analysis and investigate of the market[8], we decide to use the AS-6 as the high secondary refrigerant and use the dichloromethane as the low secondary refrigerant. The physical property parameter is shown in the table 1. The freezing point of the AS-6 is -55℃. It hasn’t flash point, meet the requirement of the high secondary refrigerant. The low secondary refrigerant of the climatic facility using the dichloromethane. The physical property parameter of the dichloromethane is shown in the table 2.

| Table 1. The physical property parameter of AS-6 |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Temperature (℃) | Viscosity (ep)  | density (g/cm³) | Heat conductivity Coefficient (W/m/k) | Specific heat (KJ/kg/K) |
| -50             | 54.7            | 1.388           | 0.38                         | 2.55             |
| -40             | 25.7            | 1.383           | 0.39                         | 2.57             |
| -30             | 11.96           | 1.378           | 0.41                         | 2.58             |
| -20             | 8.70            | 1.370           | 0.42                         | 2.59             |
| -10             | 5.31            | 1.368           | 0.43                         | 2.60             |
| 0               | 3.87            | 1.366           | 0.44                         | 2.61             |
| 10              | 3.53            | 1.362           | 0.45                         | 2.61             |
| 20              | 3.20            | 1.358           | 0.47                         | 2.62             |
| 40              | 2.3             | 1.338           | 0.53                         | 2.74             |
| 80              | 1.4             | 1.316           | 0.57                         | 2.82             |

| Table 2. The physical property parameter of the dichloromethane |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Temperature (℃) | Viscosity (ep)  | density (g/cm³) | Heat conductivity Coefficient (W/m/k) | Specific heat (KJ/kg/K) |
| -70             | 0.8064          | 1.480           | 0.1892                      | 1.2339           |
| -60             | 0.7545          | 1.464           | 0.1858                      | 1.1242           |
| -50             | 0.7023          | 1.448           | 0.1825                      | 1.2392           |
| -40             | 0.6589          | 1.431           | 0.1791                      | 1.1288           |
| -30             | 0.6153          | 1.414           | 0.1757                      | 1.1317           |

When the test temperature in the laboratory is above -25 ℃, the secondary refrigerants of medium or high temperature exchanges cooling with the refrigerants of high temperature-R507. When the test temperature in the laboratory is below -25 ℃, the secondary refrigerants of medium and high temperature exchanges cooling with the refrigerants of low temperature- R23 in the refrigeration system.

3. The design of the secondary refrigerant storages
After the secondary refrigerants are determined, the number and size of the secondary refrigerant storages should be designed according to the cooling requirement and the physical property parameters of the secondary refrigerants.
3.1. The flow of the secondary refrigerant AS-6

AS-6 treats the moist air from 35 °C to -25 °C, AS-6 flowing out of the brine storage is -35°C, AS-6 flowing into the brine storage is -7.07°C. The relevant parameters to be used for calculation are as follows:

The dry bulb temperature of the handling moist air is 35 °C, the wet bulb temperature is 25.8 °C. According to the table, the moisture content of the moist air is \( d_1 = 17 \text{ g/kg} \), the moisture content of the saturated air at -25 °C is \( d_2 = 0.38 \text{ g/kg} \). The latent heat is \( Q_1 = 2257 \text{ KJ/s} \) when the water is changed into vapor. The melting heat of the ice is \( Q_{\text{melt}} = 334.72 \text{ KJ/s} \). The air compensation is 400 kg/s, there are 5 FMAUs, the air flow rate of each FMAU is 80 kg/s, and the specific heat capacity of the air is \( c = 1.005 \text{ KJ/kg K} \), the moisture content of 80 kg/s moist air is \( d_3 = 16.7 \text{ g/kg} \).

The calculation of the flow is as follows.

The water content in the moist air can be obtained as follows:

\[
M_{\text{water}} = m \times (d_1 - d_2) = 80 \times (16.7-0.38) \times 10^{-3} = 1.306 \text{ kg}
\] (1)

The dry air content in the moist air can be obtained as follows:

\[
m = 80 - 1.306 = 78.694 \text{ kg}
\] (2)

The calculation of the cooling needed when the vapor changed from 35 °C to 0 °C can be expressed as:

\[
Q_1 = m \cdot c \cdot \Delta T = 1.306 \times 4.2 \times 35 = 191.9 \text{ KJ/s}
\] (3)

The calculation of the cooling needed when the vapor changed to the water can be expressed as:

\[
Q_2 = m \cdot Q_1 = 1.306 \times 2257 = 2947.6 \text{ KJ/s}
\] (4)

The latent heat when the water changed to the ice can be calculated as:

\[
Q_3 = m \times Q_{\text{melt}} = 1.306 \times 334.72 = 437.14 \text{ KJ/s}
\] (5)

The cooling when the ice at 0 °C changed to the ice at -25 °C can be calculated as:

\[
Q_4 = m \cdot c \cdot \Delta T = 1.306 \times 2.1 \times 25 = 68.54 \text{ KJ/s}
\] (6)

The cooling when the dry air at 35 °C changed to the dry air at -25 °C can be calculated as:

\[
Q_5 = m \cdot c \cdot \Delta T = 1.005 \times 60 \times 78.694 = 4745.24 \text{ KJ/s}
\] (7)

The compensation air from 35°C to -25°C can be calculated as:

\[
Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 = 191.9 + 2947.6 + 437.14 + 68.54 + 4745.24 = 8390.42 \text{ KJ/s}
\] (8)

The density of the AS-6 at -35°C is \( \rho = 1378 \text{ kg/m}^3 \), the specific heat is \( C_o = 2.57 \text{ J/(g} \cdot \text{K)} \).

The temperature difference of the AS-6 between the inlet and outlet is:

\[
\Delta T = 35 - 7.07 = 27.93 \text{ °C}
\] (9)

The volume flow rate of AS-6 is:

\[
V = \frac{Q}{(\rho \cdot C_o \cdot \Delta T)} = \frac{8390.42}{1378 \times 2.57 \times 27.93} = 0.082 \text{ m}^3/\text{s} = 82 \text{ L/s}
\] (10)

3.2. The flow of the secondary refrigerant—dichloromethane

Dichloromethane treats the Saturated air from -25 °C to -55 °C, Dichloromethane flowing out of the brine storage is -63°C, Dichloromethane flowing into the brine storage is -41.96°C.

The flow of the air is 80 kg/s, the temperature difference of the air is:
The cooling needed when the air is handled can be calculated as follows:

$$\Delta T = 55 - 25 = 30 \degree C$$  \hspace{1cm} (11)$$

$$Q = m \cdot c \cdot \Delta T = 1.005 \times 80 \times 30 = 2412 \text{ KJ/s}$$  \hspace{1cm} (12)$$

The density of dichloromethane is $$\rho = 1487 \text{ kg/m}^3$$.

The specific heat of dichloromethane at -63$\degree$C is $$c_o = 0.903 \text{ KJ/(kg} \cdot \text{K)}$$

The temperature difference of dichloromethane between the inlet and outlet can be obtained as follows:

$$\Delta T_0 = T_2 - T_1 = 21.04 \text{ K}$$  \hspace{1cm} (13)$$

The volume flow rate of dichloromethane is:

$$V = \frac{Q}{(\rho \cdot c_o \cdot \Delta T)} = \frac{2412}{1487 \times 0.903 \times 21.04} = 0.0853 \text{ m}^3/\text{s} = 85.3 \text{ L/s}$$  \hspace{1cm} (14)$$

3.3. The number and the size of the brine storage

The cooling storage capacity can provide 20 minutes of the test demand every 4 hours.

Due to incomplete stratification and interference of the inlet and outlet, it is assumed that only 90% of brine in the tank can be used for the experiment. The other 10% offset the energy loss caused by the start, pump, fan and pipeline accessories.

The design flow of AS-6 is 82L/s, and the volume of AS-6 which is required is:

$$82 \text{ L/s} \times 20 \text{ min} \times 1.2 \text{(consume)} = 118.08 \text{ m}^3/\text{Unit}$$  \hspace{1cm} (15)$$

There are 5 tanks, each one has a volume of 118.08m$^3$.

The design flow of dichloromethane is 213.4L/s, and the volume of dichloromethane which is required is:

$$85.3 \text{ L/s} \times 20 \text{ min} \times 1.2 \text{(consume)} = 99.809 \text{ m}^3/\text{Unit}$$  \hspace{1cm} (16)$$

There are 5 tanks, each one has a volume of 99.809m$^3$.

3.4. The design of the brine storage

The design of the brine storage tanks is mainly used for the cooling / heat storage for the secondary refrigerant in the engine running in the laboratory. As the total air compensation of the laboratory is 400kg / s, the storage tanks of the medium or high temperature refrigerant AS-6 are designed to be 5, each volume is 118.08m$^3$. The storage tanks of low temperature refrigerant dichloromethane are designed to be 5, each volume is 99.809m$^3$.

4. Conclusions

In order to maintain the normal operation of the engine starting in the laboratory, the air first passes through the cooling coil with refrigerant AS-6, then passes through the cooling coil with refrigerant dichloromethane, and finally enters the engine test room. The higher the engine thrust, the more air is consumed. Therefore, the faster the salt water is consumed, the shorter the duration time is.

The cooling capacity stored in the refrigerant storage tank can continuously provide about 80 kg / s of air at -55 $\degree$C for 20 minutes, which can meet the requirement of running an engine with an exhaust speed of 204.3 kg / s for 20 minutes.

The cold storage system designed in this paper can meet the cooling demand of the engine start-up test in the laboratory, and provide technical support for the later test capacity expansion of the aircraft in the climate environment laboratory.

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