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The Design of a Shell-Tube Heat Exchanger as Evaporator an Absorption Chiller Cycle to Reduce the Temperature of the Air Entering a Diesel Engine Operating at Full Load Engine Medium

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Abstract

Survey, design evaporator heat exchanger is an absorption chiller cycle. To cooling air to a four-cylinder diesel engine medium, at full load at different speeds to increase the useful power output. Heat can be recycled to cooling air to the engine, by the absorption chiller, cooling to be converted. By reducing the engine inlet air temperature by evaporating, at full load, increased air density. And consequently more engine volumetric efficiency. As a result, the effective power output increases. In this study, the design of the structure of the evaporator, Solid Works was done by software. And the relationship between formulas and equations of heat transfer in the MATLAB code and the output results is provided in this article.

Keywords: evaporators, absorption chillers

1. Introduction

In this study, the performance of the heat exchanger shell - tube evaporator is used to design. Geometry calculations evaporator, which is considered to be in a range of sizes are reasonable. And in the applicable building and the space limitations, there was not a problem. Evaporator in a heat exchanger shell - tube is considered. In the case of evaporators, air passes from the compressor and the evaporator tubes, a mixture of saturated ammonia flows. Exhaust air from the compressor, with a high temperature and pressure. So through the shell evaporator, thermal energy to the mixture of ammonia saturated and cooled. On the other hand, a mixture of saturated ammonia in the evaporator tubes, thermal energy from the air entering the evaporator. And it was converted to ammonia. The fluid flows in the shell and tube evaporators, parallel. It is intended as a cylindrical shell evaporator. The evaporator tubes, radically and symmetrically were placed inside the shell.

In Tables 1 to 4, properties of air entering the evaporator (air outlet of the compressor) in a different period in the case of diesel engines operating under full load is given. Evaporators for thermal analysis and measuring the properties were used.

Table 1. The temperature of the air entering the evaporator at the various speeds at full load

	$1000(rpm)$	$2000(rpm)$	$3000(rpm)$	$4000(rpm)$
$T_{inlet}(k)$	373	393	413	433

Table 2. The pressure of air entering the evaporator at the various speeds at full load

	$1000\ (rpm)$	$2000\ (rpm)$	$3000\ (rpm)$	$4000\ (rpm)$
$P_{inlet}(bar)$	1.2	1.6	1.65	1.7

Table 3. The mass flow rate of air entering the evaporator at the various speeds at full load

	$1000(rpm)$	$2000(rpm)$	$3000(rpm)$	$4000(rpm)$

$\dot{m}_{inlet}(\frac{kg}{s})$	0.021	0.06	0.086	0.127

Table 4. The density of air entering the evaporator at the various speeds at full load

	$1000(rpm)$	$2000(rpm)$	$3000(rpm)$	$4000(rpm)$
$\rho_{inlet}(\frac{kg}{m^3})$	1.12	1.43	1.4	1.38

Properties introduced the diesel engine in the cycle absorption chiller

Choice of four-cylinder diesel engine, a diesel motors are heavy. In some of the trucks and also in some industries, is used.

Geometry of four-cylinder diesel engine is given in Table 5.

Table 5. Four-cylinder diesel engine geometry

Bore	(mm) 90
Stroke	(mm) 100
Compression ratio	16.5
Connecting rod length	(mm) 220
TDC clearance heigh	(mm) 0.5
Inlet Valve-Open Timing Angle	351.276 (4-Stroke CA)
Inlet Valve-Closing Timing Angle	623.59 (4-Stroke CA)
Exhaust Valve-Open Timing Angle	125.276 (4-Stroke CA)
Exhaust Valve-Closing Timing Angle	397.59 (4-Stroke CA)

The size of the internal diameter of the cylinder: Bore))

The size of the stroke: Stroke))

The Compression Ratio: Compression ratio))

The length of the rod interface: Connecting rod length))

Distance from the edge of the piston of the engine block at the top:

TDC clearance height))

The timing of valve opening:

(Valve - Open Timing Angle)

The timing of closing of the valve:

(Valve - Closing Timing Angle)

In this study, absorption chiller

The absorption chiller discussed in this review, liquid ammonia as the refrigerant and water as the absorbent fluid is considered. Ammonia emitted from the condenser is cooled to liquid form. Ammonia fluid passes through a pressure breaker valve, a low pressure liquid ammonia conversion. And push it to the evaporator pressure will work. Entrance of the evaporator, liquid ammonia pressure is low and the engine air intake. So that ammonia as liquid cooling and air to the engine, as the fluid is considered. The hot air entering the engine, passes through the evaporator is cooled by ammonia and then cooled to a certain temperature into the engine. After the temperature inside the evaporator liquid ammonia is converted to ammonia. And then enter the adsorbent chamber. The evaporator, a shell and tube heat exchanger can be considered. So that a mixture of saturated ammonia in the pipes flowing. And the shell, the air passes. The adsorbent chamber, ammonia and water solution and dilute ammonia cooled, mixed with each other. And thus concentrated solution of water and ammonia is created. Concentrated solution of ammonia and cold pressure water by a pump to push the generator is working. And the path before entering the generator, pre-heated. The pre-heated water and concentrated ammonia go into the generator. Hot fluid inside the generator, the engine exhausts gases. And a solution of water and ammonia in the generator, thermal energy from the engine exhaust gases. As a result, the amount of ammonia gas to be converted. And a mixture of water and ammonia are separated.

Diluted ammonia solution and hot water, leave the generator through a heat exchanger. To preheat the hot and dense mixture of water and ammonia is used as the input to the generator. And hot steams to the condenser exhaust gas temperature ammonia after the move. And so, the cycle is completed. The temperature of the exhaust gases, after leaving the generator is reduced and transferred to the environment.

Engine exhaust gases due to soot particles, causing plenty of deposits into the generator. Thus, the exhaust gas before entering the generator, through a cyclone passed. Exhaust gas flow within the cyclone, so that the soot particles deposited in the cyclone. Generator exhaust gas outlet pipe into the cyclone 4 and 3. [This reduces the amount of sediment in the pipes leading to the gas generator.

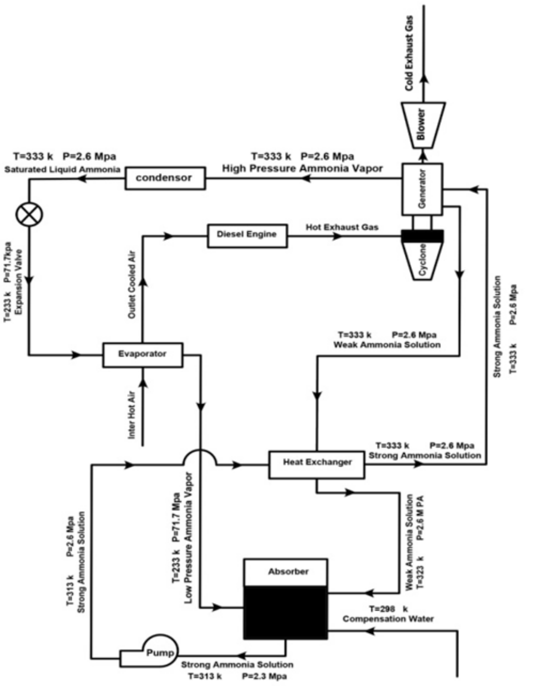

Figure 1. Schematic of absorption chiller cycle and diesel engines

The mass flow rate of water and ammonia absorption chiller cycle, at different engine speeds, has been different. So that a flow rate regulator, in order to create the desired mass flow rate used in each round.

Graph of water and ammonia flow rate changes, the different engine speeds shown in the following figure.

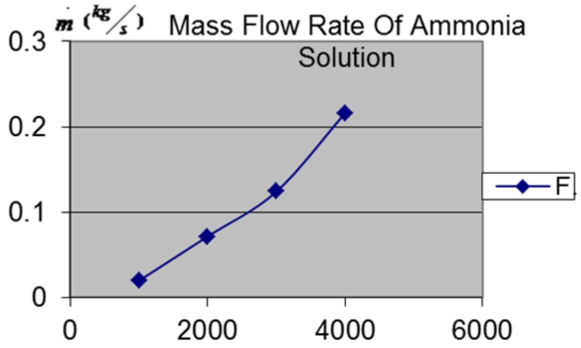

Figure 2. change the mass flow rate of water and ammonia absorption chiller cycle with the engine speed

Within generators, 27% of ammonia in water and ammonia evaporates. Mass flow rate of water and ammonia. 30% of the mass of dissolved ammonia form. Since the generator is saturated with ammonia in the mixture, the temperature for the ammonia does not occur while the temperature of the water inside the generator is increased, on the other hand the exhaust gas temperature as the fluid is intended to reduce will.

The temperature of the incoming water and ammonia generator is. Saturation temperature of the water is greater than the pressure generator so water does not evaporate inside the generator.

2. Analysis of Temperature and Pressure Evaporator

Ammonia output from the expansion valve is saturated in mixed mode, the remaining liquid ammonia enters the evaporator and the mixture is evaporated in the evaporator. Ammonia, when entering the evaporator temperature and pressure of 71.7 kPa on the mixture is saturated.

A mixture of saturated ammonia in the evaporator, the constant pressure heat from the gas inlet to the engine and therefore the ammonia is evaporated in the evaporator outlet. In the evaporator outlet, ammonia in the form of saturated steam at a temperature and pressure is 71.7 kPa. The amount of heat absorbed by liquid ammonia to evaporate within the evaporator, the equation (1) is obtained:

$$Q_{ev} = \dot{m}_{amev} \times (1 - x) \times h_{fgam@P=71.7(Kpa)}$$

Average thermal capacity constant pressure, air flow through the evaporator shell, according to the following equation to be determined:

$$(2)\ \ C_{Pmair} = \frac{C_{Pairinev} + C_{Pairoutev}}{2}$$

Thermal capacity constant pressure of air entering the evaporator (air output of the compressor motor), and the constant pressure heat capacity of the evaporator outlet air is.

A view of the air inlet and outlet sections of the evaporator shell, in Figure 3, is shown.

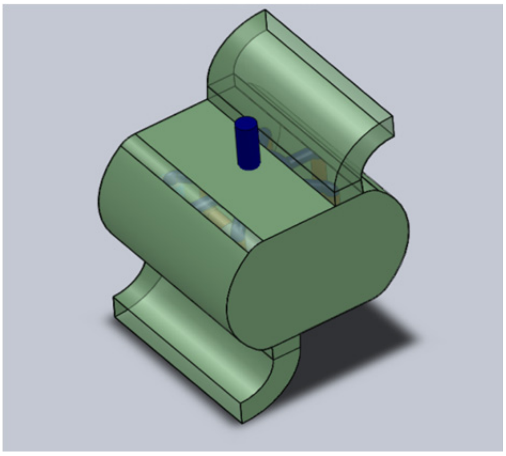

Figure 3. The air inlet and outlet sections of the evaporator shell

Since the air naturally contains some moisture (water vapor) is. If the temperature of the exhaust air from the evaporator to cool the evaporator, which is less than the water vapor in the air, the temperature has decreased. And thrush appears. In this case, the heat lost by moisture in the air, we have:

$$Q_{frost1} = \dot{m}_{water\ in\ air} \times C_{Pwater} \times (T_{airinev} - 0) \tag{3}$$

$$Q_{frost2} = \dot{m}_{water\ in\ air} \times C_{fwater} \tag{4}$$

$$Q_{frost} = Q_{frost1} + Q_{frost2} \tag{5}$$

The amount of moisture in the air to consider:

$$\omega = 0.7 \tag{6}$$

Mass of moisture in the air, in the form of equation (7) is obtained:

$$water\ percent\ in\ air = \frac{\omega}{1+\omega} \tag{7}$$

The moisture in the air mass flow rate, according to equation (8) is:

$$\dot{m}_{water\ in\ air} = \dot{m}_{air\ in\ ev} \times \left(\frac{\omega}{1+\omega}\right) \tag{8}$$

Heat lost by air to reduce the temperature, the equation appears:

$$Q_{evair} = Q_{ev} - Q_{frost} \tag{9}$$

Therefore, the temperature of the exhaust air from the evaporator, thus obtained:

$$T_{airoutev} = T_{airinev} - \frac{Q_{evair}}{\dot{m}_{evair} \times C_{Pmair}} \tag{10}$$

To evaluate the level of heat transfer in the evaporator

The number of tubes in the evaporator is 8 and the symmetrical length of pipe within the evaporator to consider 7 cm. And the vertical pipes in the evaporator with the blade length of 28.6 cm in size. The length of the main pipe within the evaporator, 28.6 cm is considered.

The length of the top tube evaporators, internal diameter is 4 cm and 20 cm to be. The total length of the evaporator tubes, 42.6 cm can be achieved. The thickness of the evaporator tubes, 0.00338 inches, the outer diameter of the pipe inner diameter of 0.0334 inches and 0.0266 inches, will be considered.

Sex in the evaporator tubes, aluminum is selected. Because it is lighter and has less weight. As well as aluminum, in the range of operating temperature evaporators, heat resistance is necessary. Therefore, the thermal conductivity of the evaporator tubes is:

$$k_{ev} = 200\left(\frac{w}{m.k}\right) \tag{11}$$

Effective area of the evaporator heat transfer, is obtained from the following equation:

$$A_{ev} = Nt_{ev} \times D_{otubeev} \times l_{tubeev} \times \pi \tag{12}$$

Above equation, the number of the evaporator tubes, outer diameter and tube evaporator, overall length of pipe is inside the evaporator.

With the result, the evaporator heat transfer coefficient, thermodynamic point of view as regards (13), is calculated:

$$U_{ev} = \frac{AU}{A_{ev}} \tag{13}$$

Assessing the overall coefficient of heat transfer in the evaporator

Ammonia within the evaporator, the mixed flow temperature is saturated. Properties ammonia evaporator inlet, is at saturation mixing properties. And its properties at the evaporator outlet, the properties of ammonia vapor are at.

Specific volume of ammonia, when mixed saturation temperature, in accordance with the following information:

$$v_{famev} = 0.00145\left(\frac{m^3}{kg}\right) \tag{14}$$

$$v_{fgamev} = 1.55111\left(\frac{m^3}{kg}\right) \tag{15}$$

$$v_{gamev} = 1.55256\left(\frac{m^3}{kg}\right) \tag{16}$$

Specific volume of ammonia in the evaporator inlet, is obtained from the following equation:

$$v_{aminlet} = v_{famev} + x \times v_{fgamev} \tag{17}$$

Specific volume of ammonia in the evaporator outlet, according to the following equation to be determined:

$$v_{amoutlet} = v_{gamev} = 1.55256\left(\frac{m^3}{kg}\right) \tag{18}$$

Average volume for ammonia within the evaporator, the equation (19) is obtained:

$$v_{meanam} = \frac{v_{aminlet}+v_{amoutlet}}{2} \tag{19}$$

The average density of ammonia, is:

$$\rho_{meanam} = \frac{1}{v_{meanam}} \tag{20}$$

Cross section passing through the evaporator tube in accordance with the following formula is obtained:

$$A_{\mathrm{iev}} = \frac{\pi \times D_{iev}^2}{4} \tag{21}$$

The ammonia flow rate through the evaporator tubes, the following formula is set:

$$V_{amev} = \frac{v_{meanam} \times \dot{m}_{amev}}{A_{\mathrm{iev}} \times \mathrm{Nt_{ev}}} \tag{22}$$

Viscosity coefficient of liquid ammonia saturation, the temperature is equal to:

$$\mu_{aml@T=-40c^0} = 280.8 \times 10^{-6}(pa.s) \tag{23}$$

And viscosity coefficient of ammonia at atmospheric pressure, is equivalent to:

$$\mu_{amvap@T=-40c^0} = 8.353 \times 10^{-6}(pa.s) \tag{24}$$

Thus, the coefficient of viscosity mixture of saturated ammonia when entering the evaporator, according to the following equation:

$$\mu_{amevinlet} = x \times \mu_{amvap@T=-40c^0} + (1-x) \times \mu_{aml@T=-40c^0} \tag{25}$$

Viscosity coefficient ammonia vapor leaving the evaporator, is equivalent to:

$$\mu_{amevoutlet} = \mu_{amvap@T=-40c^0} = 8.353 \times 10^{-6}(pa.s) \tag{26}$$

The average coefficient of viscosity of fluid ammonia within the evaporator, the equation (27), characterized:

$$\mu_{amevmean} = \frac{\mu_{amevinlet}+\mu_{amevoutlet}}{2} \tag{27}$$

Thus, the Reynolds number flow of ammonia within the evaporator tubes, obtained in accordance with the following formula:

$$Re_{amev} = \frac{\rho_{meanam} \times V_{amev} \times D_{iev}}{\mu_{amevmean}} \tag{28}$$

For fully developed turbulent flow through the evaporator tubes are:

$$\frac{x}{l} = Re_{amev}^{-0.75} \tag{29}$$

Prantel number for saturated liquid ammonia is:

$$pr_{aml@T=-40c^0} = 2.28 \tag{30}$$

Prantel number ammonia vapor, is equivalent to:

$$pr_{amvap@T=-40c^0} = 0.91 \tag{31}$$

Therefore, the number Prantel saturated mixture of ammonia in the evaporator inlet, according to equation (32), is calculated:

$$pr_{amevinlet} = x \times pr_{amvap@T=-40c^0} + (1-x) \times pr_{aml@T=-40c^0} \tag{32}$$

Liquid ammonia, to exit from the evaporator with Prantel number is as follows:

$$pr_{amevoutlet} = pr_{amvap@T=-40c^0} = 0.91 \tag{33}$$

Calculated convective heat transfer coefficient in the evaporator tubes

When flow conditions within the pipeline, it is true:

$$2300 < Re_{amev} < 10000 \tag{34}$$

And

$$0.5 < pr_{amevmean} < 2000 \tag{35}$$

Then, according to the correction factor Filouninko Khirilof Petoukhouf-, Nusselt ammonia fluid into the evaporator tubes, from (36), follows:

$$Nu_{amev} = \frac{\left(\frac{Filonenko}{2}\right)\times(Re_{amev}-1000)\times pr_{amevmean}}{1+12.7\times\left(\frac{Filonenko}{2}\right)^{\frac{1}{2}}\times(pr_{amevmean}^{\frac{2}{3}}-1)} \tag{36}$$

So that Filouninko factor, according to the following equation, is obtained:

$$Filonenko = \frac{1}{(1.58\times\log(Re_{amev})-3.28)^{2}} \tag{37}$$

If ammonia flow through the evaporator tubes, other conditions as follows, is true:

$$Re_{amev} < 2300 \tag{38}$$

$$0.48 < pr_{amevmean} < 16700 \tag{39}$$

$$0.044 < \frac{\mu_{bev}}{\mu_{wallev}} < 9.75 \tag{40}$$

Under the conditions mentioned, Nusselt relationship will follow.

$$Nu_{amev} = 1.86 \times (Re_{amev} \times pr_{amevmean} \times \frac{D_{iev}}{l_{tev}})^{\frac{1}{3}} \times (\frac{\mu_{amevmean}}{\mu_{amwall}})^{0.14} \tag{41}$$

So that the viscosity coefficient of ammonia at the inner wall of the evaporator tubes is:

$$\mu_{amwall} = 280.82 \times 10^{-6}(pa.s) \tag{42}$$

Thermal conductivity of saturated liquid ammonia at a temperature equal to:

$$k_{aml@T=-40c^{0}} = 0.547(\frac{w}{m.k}) \tag{43}$$

Ammonia vapor temperature and thermal conductivity, is equivalent to:

$$k_{amvap@T=-40c^{0}} = 0.02(\frac{w}{m.k}) \tag{44}$$

Therefore, the thermal conductivity of saturated ammonia mixture at the entrance of the evaporator, by equation (45) is obtained:

$$k_{amevinlet} = x \times k_{amvap@T=-40c^{0}} + (1-x) \times k_{aml@T=-40c^{0}} \tag{45}$$

Thermal conductivity of ammonia in the evaporator outlet, is:

$$k_{amevoutlet} = k_{amvap@T=-40c^{0}} = 0.02(\frac{w}{m.k}) \tag{46}$$

Therefore, the thermal conductivity of the fluid average ammonia within the evaporator, obtained as follows:

$$k_{amevmean} = (\frac{k_{amevinlet}+k_{amevoutlet}}{2}) \tag{47}$$

Thus, the thermal conductivity convective flow of ammonia within the evaporator, according to equation (48), is determined:

$$h_{amev} = \frac{Nu_{amev}\times k_{amevmean}}{D_{iev}} \tag{48}$$

Video of the evaporator tubes, which passes through the ammonia, is shown in Figure 4.

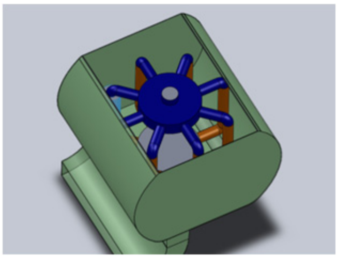

Figure 4. A view of the layout of the evaporator tubes

Also, a longitudinal section of the evaporator, in order to show the blades on the evaporator tubes, in Figure 5, is depicted.

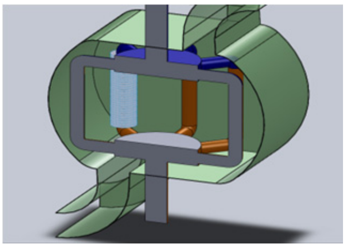

Figure 5. View of the blades on the evaporator tubes

Calculated convective heat transfer coefficient of the air inside the evaporator shell

Evaporator shell into a rectangular container with dimensions of 510 mm and 520 mm is intended.

Such a cross-section of the evaporator shell is obtained:

$$A_{evshell} = 0.2652(m^2) \tag{49}$$

And the evaporator shell, the result will be:

$$P_{evshell} = 2.06(m) \tag{50}$$

Evaporator input cross section is calculated as:

$$A_{header} = \frac{\pi \times D_{header}^2}{4} \tag{51}$$

Thus, the cross-section of the evaporator shell gas flows at the inlet to the engine, according to equation (52), is determined:

$$A_{effevshell} = A_{evshell} - Nt_{ev} \times l_{pipehor\times} D_{oev} - A_{header} \tag{52}$$

In the above equation, the number of tubes in the evaporator and evaporator is over the horizontal pipes.

The shell of the evaporator, also determined according to the following equation:

$$P_{effevshell} = P_{evshell} + Nt_{ev} \times l_{pipehor\times} 2 + \pi \times D_{header} \tag{53}$$

The hydraulic diameter of the evaporator shell, according to the following equation:

$$D_{hevshell} = \frac{4 \times A_{effevshell}}{P_{effevshell}} \tag{54}$$

By calculating the diameter hydraulic, hydraulic cross-section of the evaporator shell, characterized as follows:

$$A_{hyd} = \frac{\pi \times D_{hevshell}{}^2}{4} \tag{55}$$

To calculate the average density of the air inside the evaporator shell, we use the following equation:

$$\rho_{airevmean} = \frac{\rho_{airevinlet} + \rho_{airevoutlet}}{2} \tag{56}$$

Then, according to the following formula, the speed of air in the shell can be achieved:

$$V_{airev} = \frac{\dot{m}_{airev}}{\rho_{airevmean} \times A_{hyd}} \tag{57}$$

The viscosity index of the average airflow through the evaporator shell, the equation (58), is determined:

$$\mu_{airevmean} = \frac{\mu_{airevinlet} + \mu_{airevoutlet}}{2} \tag{58}$$

Thus, the Reynolds number flow into the evaporator, it is obtained:

$$Re_{evshell} = \frac{\rho_{airevmean} \times V_{airev} \times D_{hevshell}}{\mu_{airevmean}} \tag{59}$$

Prantel number of air flow through the evaporator shell, according to the following equation is obtained:

$$pr_{airevmean} = \frac{pr_{airevinlet} + pr_{airevoutlet}}{2} \tag{60}$$

Nusselt, for air flow through the evaporator shell (going on a bundle), the following equation is calculated:

$$Nu_{evshell} = 0.27 \times C_{nev} \times Re_{evshell}^{0.63} \times pr_{airevmean}^{0.36} \times (\frac{pr_{airevmean}}{pr_{wallevshell}})^{0.25} \tag{61}$$

In relation to the above parameters, Prantel number of air at the evaporator shell wall, the phase change temperature is ammonia. Quantity, the correction factor is high in relation to its value on the graph, is 0.75. Thermal conductivity mean airflow through the evaporator shell, according to equation (62) is obtained:

$$k_{airevmean} = \frac{k_{airevinlet} + k_{airevoutlet}}{2} \tag{62}$$

The displacement of air within the shell of the evaporator heat transfer coefficient, the equation (63), the result will be:

$$h_{evshell} = \frac{Nu_{evshell} \times k_{airevmean}}{D_{hevshell}} \tag{63}$$

Due to the fact that, within the evaporator finned tube is intended, the coefficient of efficiency of the blades is considered as follows:

$$\eta_{evfin} = 0.2 \tag{64}$$

Thus, the overall coefficient of heat transfer in the evaporator, the relationship will be determined by:

$$U_{ev} = (IDF) \times \frac{1}{\frac{D_{oev}}{D_{iev} \times h_{evam}} + \frac{D_{oev} \times r_{fiev}}{D_{iev}} + \frac{D_{oev} \times \log(\frac{D_{oev}}{D_{iev}})}{2 \times k_{tubev}} + \frac{r_{foev}}{\eta_{evfin}} + \frac{1}{h_{evshell} \times \eta_{evfin}}} \tag{65}$$

So that (IDF) the top of the coefficient is about to come true and it is considered to be 0.7.

3. Results

In this section results in the reduction of the engine inlet air temperature by evaporating, at full load engine performance is presented.

In Fig. 6, 7 and 8, respectively, temperature and density of the air mass by the evaporator and the mass density of air entering the engine cooling preoperative period and various motor shows:

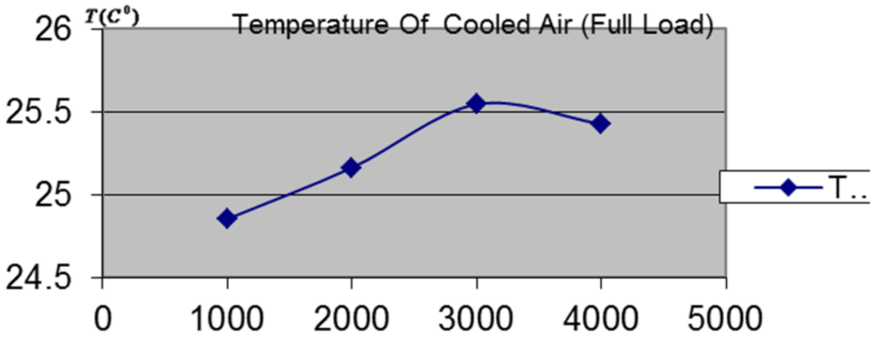

Figure 6. outlet air temperature of the evaporator at the various speeds at full load

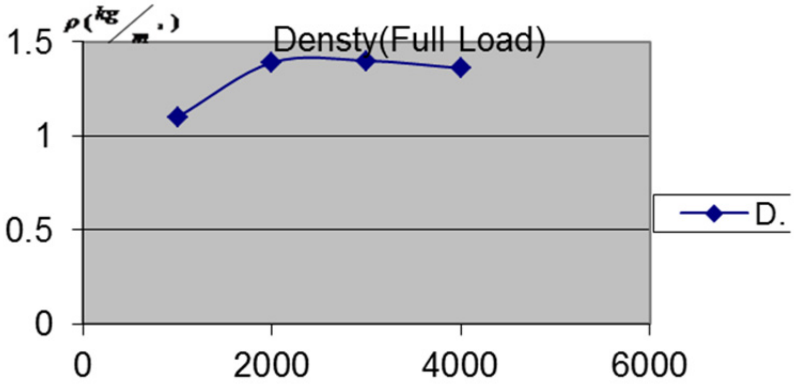

Figure 7. The density of air entering the engine cooling period before full load

According to Figure 7, 3000 air density is highest. And changes in the density of air entering the engine at different speeds, depending on temperature and air pressure input. The cooling air density will be increased in each round. The result of the comparison of Figures 7 and 8 together, the result will be. So that by increasing the density of the air, the volumetric efficiency of the engine and thus more useful power output of the engine will increase.

List of Symbols

Overall coefficient of heat transfer $U\,(W/m^2.k)$

Prantel number pr

Reynolds number Re

Nusselt Nu

Filouninkou factor $Filonenko$

Thermal conductivity $K(W/mk)$

Hydraulic diameter $D(m)$

Speed $V\,(m/s)$

Level $A(m^2)$

Density $\rho\,(kg/m^3)$

Viscosity index $\mu(pas.s)$

Specific volume $v\,(m^3/kg)$

Length $l(m)$

Thickness $t(m)$

Temperature $T(k)$

Mass flow rate $\dot{m}\,(kg/s)$

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