RESEARCHES ON THE TESTING IN LABORATORY CONDITIONS OF AN ECOLOGICAL CLIMATE SYSTEM USED FOR SELF-PROPELED AGRICULTURAL MACHINES
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CERCETĂRI PRIVIND TESTAREA ÎN CONDIŢII DE LABORATOR A UNUI SISTEM DE CLIMATIZARE ECOLOGIC FOLOSIT LA MAŞINILE AGRICOLE AUTOPROPULSATE

Găgeanu Iuliana, Cujbescu Dan*, Dumitru Cristinel
INMA Bucharest / Romania;
**E-mail: dcujbescu@yahool.com*
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ABSTRACT
Nowadays, cooling the air by means of climate maintenance systems is achieved, in most cases, using installations based on freon or other substances that cause pollution. Taking into account the fact that the EEC standards and regulations increase the emphasis on ensuring the quality, labour safety, health and environment, finding a solution for air conditioners that do not use a substance that causes pollution, has become a necessity. As a great part of farming work is done in the warmest periods of the year, temperatures being frequently over 35°C, it is necessary to equip the agricultural machines with air conditioners in order to achieve a thermic comfort in the cab. For this purpose, an air conditioner based on the process of water evaporation was designed, made and tested. The installation is able to cool the air that enters into the cab through the evaporation process that takes place in the special filling, with an efficiency of the mixing process more than 90%. Air passing sections are calculated so that they can assure both the quantity needed for climate maintenance in the cab (about 3.5 - 4 m^3/min) and the relative speed between air and water in the filling, in order for the evaporation process to be conducted in the best conditions that were theoretical established.

ABSTRACT
În zilele noastre, răcirea aerului prin sistemele de menținere a climei se realizează, în majoritatea cazurilor, folosind instalații bazate pe freon sau alte substanțe care provoacă poluare. Ținând cont de faptul că standardele și reglementările CEE sporesc accentul pus asupra asigurării calității, siguranței muncii, sănătății și mediului, găsirea unei soluții pentru aparatele de aer condiționat care nu utilizează o substanță care provoacă poluare, a devenit o necesitate. Deoarece o mare parte a muncilor agricole se face în perioadele cele mai calde ale anului, temperaturile fiind frecvent peste 35°C, este necesar să se echipeze utilajele agricole cu aparate de aer condiționat pentru a obține un confort termic în cabină. În acest scop, a fost proiectat, realizat și testat un aparat de aer condiționat bazat pe procesul de evaporare a apei. Instalația este capabilă să răcească aerul care intră în cabină prin procesul de evaporare care are loc în umplutura specială, cu o eficiență a procesului de amestecare mai mare de 90%. Secțiunile de trecere ale aerului sunt calculate astfel încât să poată asigura atât cantitatea necesară pentru întreținerea climatică a cabinei (aproximativ 3.5 - 4 m^3/min), cât și viteza relativă dintre aer și apă în umplutură, pentru ca procesul de evaporare să se desfășoare în cele mai bune condiții stabilite teoretic.

INTRODUCTION

The main functions of agricultural machinery cabs are to provide a comfortable environment for operators and to protect them from vibrations, noise and other adverse influences. Since the conditions inside self-propelled machinery cabs (agricultural tractors and other equipment) affect the health, performance and comfort of the operator, it is important to find solutions for improving these conditions (*Ruzic & Casnji, 2012*).

The most important factors influencing thermal comfort of humans operating in vehicle cabs are air velocity, temperature, clothing style, relative humidity, and level of activity of the occupants (*Afzal et al., 2020; Simion et al., 2016*).

Ensuring the comfort of the person operating the equipment is achieved both by using an ergonomic car seat and by creating a pleasant environment by air conditioning inside the cab with the help of special equipment (*Oh et al., 2020*).

In general, air-conditioning systems are complicated, they must provide the air with previously set conditions for all its characteristic parameters, thus creating an imposed artificial climate. Certain well-defined climatic conditions correspond to each organism in order to develop in optimal conditions or to give a maximum efficiency in the work process.

Thus, the amount of exterior air received by a person should not be less than 30 m^3/h, in order to avoid fatigue, headaches and nausea, caused by the lack of oxygen. Comfort conditions regarding temperature and relative humidity depending on the season must fit with some precision between the limits listed in Table 1 (*ISO 14269-2:1997; Ivanescu et al., 2010*).

Table 1

Comfort conditions regarding temperature and relative humidity

Season	Lower limit		Upper limit	
	Temperature (°C)	Relative humidity (%)	Temperature (°C)	Relative humidity (%)
Winter	16÷17	70	21÷24	70
Summer	18÷20	30	26.5÷27	70

It can be stated in principle that for a certain state of comfort, with the increase of humidity, a decrease in temperature can be admitted. The movement of air occurs both as a result of ventilation and because of temperature differences between the air layers. It is obvious that as the air speed increases, the same degree of comfort is reached at a higher temperature. For example, the effect felt in the case of an unventilated cab (resting air), where the air has 24°C and 50% humidity is the same as the effect that would be created if the air had 30°C, 50% humidity and a speed of air of 1.5 m/s^2 (*Kaufman et al., 1979*).

An air-conditioner (AC) system for a motor vehicle cab has the disadvantage that it is the largest power consumer, excluding the vehicle propulsion system. The power consumption of the AC in small tractors can reach 10-100% of the actual engine power and the highest values occur during the engine idling (*Ruzic D., 2018; Leighton & Ruth, 2016*).

Permanent change of air in the cab is necessary to replace the oxygen consumed by the driver and at the same time remove the combustion products (gases, vapours). The minimum amount of fresh air required by a person is 0.25 m^3/min (*Martinho et al., 2004*).

The comfort requirements are:

- degree of humidity in the range: 40…70%;
- the relative speed of the air must have values between 0.15…0.25 m/s, in the case of laboratory tests;
- for an outdoor temperature of 27…30°C, the limit of natural regulation by transpiration is reached;
- at a temperature higher than 35°C cardiovascular changes occur;
- at a temperature of about 40°C the person is exposed to syncope;
- the allowed comfort temperature is within the limits of 22…28 (30)°C, being strongly dependent on the air circulation speed (*ISO 14269-2:1997*).

The paper presents an ecological alternative to the classic air conditioning systems, being able to carry out the cooling of the air entering the cab through the evaporation process that takes place in the special type filling.

MATERIALS AND METHODS

Starting from the theoretical bases of the thermal and hydro-pneumatic process, an experimental model was developed that ensures a nominal flow of at least 4 m^3/min, necessary for the conditioning of the cabs of combine harvesters.

The proposed air conditioning system differs from the others used by renowned companies from abroad (in the country, the self-propelled tractors and self-propelled agricultural machineries are not equipped with an air conditioning system as such), due to the fact that it is an environmentally-friendly installation (it does not use freon or other pollutants), it is a relatively simple construction, the temperature difference achieved is, under normal conditions, 1…18 °C (above average), the installation can be used successfully even when the air humidity is high, due to the use of hygroscopic substances that retain moisture in the air, the cooled air having a low humidity.

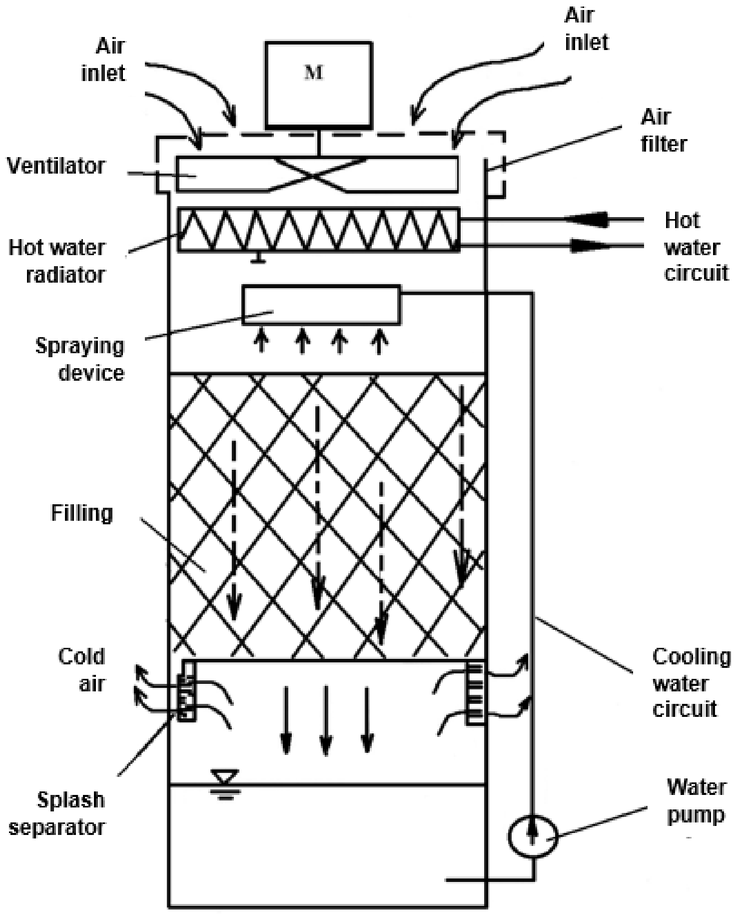

Fig. 1 - Scheme of the air conditioning system

The installation is capable of cooling the air entering the cab through the evaporation process that takes place in the special type filling, with a mixing process efficiency of over 90%.

The air passage sections are calculated so as to be able to ensure both the quantity necessary for the cab conditioning (approximately 3.5 - 4 m^3/min) and the relative speed between air and water in the filling, necessary for carrying out the evaporation process in the optimal conditions theoretically established.

Filling - an important component of this installation is the filling, chosen for this device so that it can be controlled in terms of behaviour in these conditions, through a set of mathematical relations. It is made of PVC corrugated sheets arranged on top of each other.

Fan - the air circuit of the installation presents numerous changes of the flow direction as well as local resistances, which implies the choice of a type of medium pressure fan (100…250 mm Hg). A fan whose nominal flow rate, without pneumatic resistances on the route, is 240 m^3N/hour was chosen. Taking into account that the maximum flow rate required for cab ventilation is 360 m^3N/hour, it was necessary to use two such fans.

Water pump - was chosen for the following reasons: the minimum pressure required is 0.7 m H_2O, the only significant pressure loss being the spraying device; the minimum flow of recirculated water is calculated in relation to the minimum flow of treated air and must be 7.5 l/min.

Considering these particularities, a centrifugal pump was used and a DC motor supplied at 24 V was adapted to it. Under these conditions the pressure can exceed 2.5 m H_2O and the flow rate reaches up to 28 l/min.

Spraying device - is placed in the way of the air jet, therefore its shape and dimensions must be calculated so as to oppose as little resistance as possible. On the other hand, too small dimensions lead to non-compliance with the condition of uniform spraying of the filling. Unlike other air conditioning systems based on the same operating principle, fine water spraying is not required here, so the diameter of the device holes is calculated only for reasons of flow rate and uniformity of spraying.

Water tank - The water tank has a capacity of 18 l and is made of a thermal insulation material, as well as the entire air and water circuit. The efficiency of the entire installation depends very much on the heat transfer coefficient between the environment and the water, respectively the air flowing through the installation.

Measured parameters

During the experimental determinations, the aim was first of all to measure the parameters of the air conditioning compared to those of the air admitted in the installation. It was considered to comply with the specific comfort requirements imposed by domestic and international standards, according to the comfort requirements listed above.

The following were determined:

- tank water temperature variation;
- water consumption (by periodically measuring the water level in the tank);
- water flow rate through the spraying device (indirectly, by measuring the direct current voltage applied to the motor terminals driving the water pump).

Measuring apparatus and devices

The outside air temperature was measured in the shade using a 1°C mercury thermometer. It was placed at a distance of 2 m from the ground, in a well-ventilated weather enclosure. A mercury glass thermometer with divisions of 0.5°C was used for the tank water temperature.

In order to accurately observe the temperature changes of the air conditioning, which occurred during the experiments with variable water/air flows, two electronic multimetres were used to which a thermocouple, respectively a thermal probe was attached. An electronic thermometer was placed in the cab in the operator's head area. An electronic anemometer was used to determine the air flow rate of the fan.

The water level in the tank was determined with a ruler placed on the transparent plexiglass wall of the basin, in an area where the water surface did not show turbulence caused by the operation of the pump or the free fall of water from the humidification chamber.

The humidity of the unconditioned and conditioned air, respectively, was measured with two mechanical hair hygrometers with drum recording.

The determinations were performed both at normal temperatures for the summer period in Romania and at extreme temperatures, rarely found in our country (40…41°C in the shade).

The installation was mounted successively on two cabs:

1. classic U-650 tractor cab, not equipped for conditioning;
2. C-110 P combine cab also not equipped to create thermal comfort (unsealed, no metal wall insulation, no thermal glass)

RESULTS

1. U-650 tractor cab, not equipped for air conditioning, without operator on board

Initial conditions:

- outdoor air temperature, °C: 40
- outdoor air humidity, %: 34
- temperature in the cab, °C: 47
- tank water temperature, °C: 28
- tank water level, mm: 200

Ceiling sheet temperature, °C: 51

Water consumption resulting from experiments, l/hour: 2.96

Exposed to solar radiation in conditions of outdoor temperatures of 40°C in the shade, without air conditioning or ventilation, 37°C were recorded in the cab (with the door open) at head level.

According to the experimental results it is observed that for outdoor temperatures of 40.5-41.5°C and humidity of 34%, 24.7-25.3°C were achieved at the outlet, while at the level of the operator's head were recorded 37°C and a relative humidity of 56-58% (Table 2, figures 2 - 5). The temperature of the cab ceiling was 51°C.

Table 2

Results obtained from determinations on the U-650 cab

Environment		Air conditioning					Tank water temperature	Time of determination	Voltage at pump terminals	Water level in the tank
$T_{dry.}$ (°C)	u_{rel} (%)	$t_{dry.cab}$ (°C)	$t_{dry.\ air\ cond.}$ (°C)	$t_{usc.env.}$ - $t_{dry.\ air\ cond.}$ (°C)	v_{air} (m/s)	u_{rel} (%)	(°C)	(hour:min)	(V)	(mm)
40.5	34	38	25.3	15.2	16	58	23.0	13:20	18	188
41.0	34	37	24.8	16.2	16	56	22.7	13:30	20	184
41.0	34	38	24.3	16.7	16	57	23.0	13:40	20	179
41.5	34	37	24.7	16.8	16	56	23.0	13:50	20	172
41.5	34	37	24.8	16.7	16	58	23.0	14:00	24	167
41.5	34	37	24.7	16.8	16	58	23.0	14:10	18	163

Legend:

T_{dry}= outside temperature; u_{rel} = relative humidity;

$t_{dry.cab}$ = temperature inside the cab before using air conditioning;

$t_{dry.\ air\ cond.}$ = temperature using air conditioning system

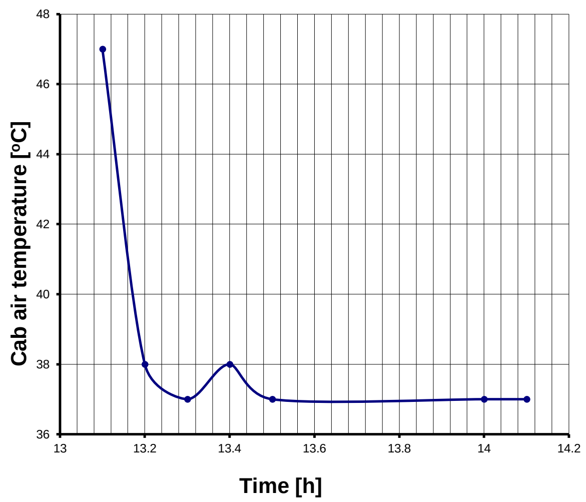

Fig. 2 - Variation of cab air temperature depending on time

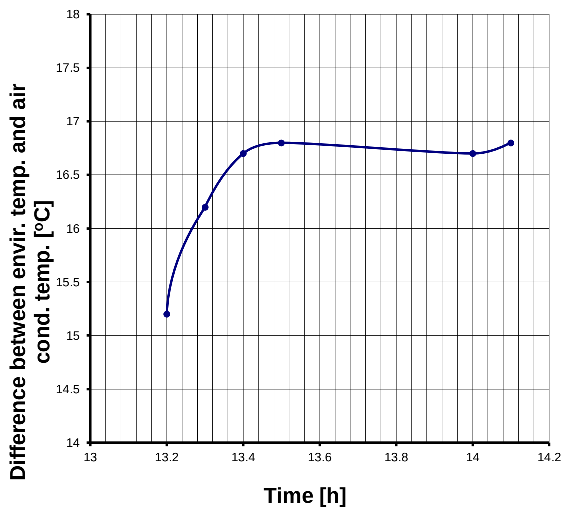

Fig. 3 - Temperature difference generated by the air conditioning system

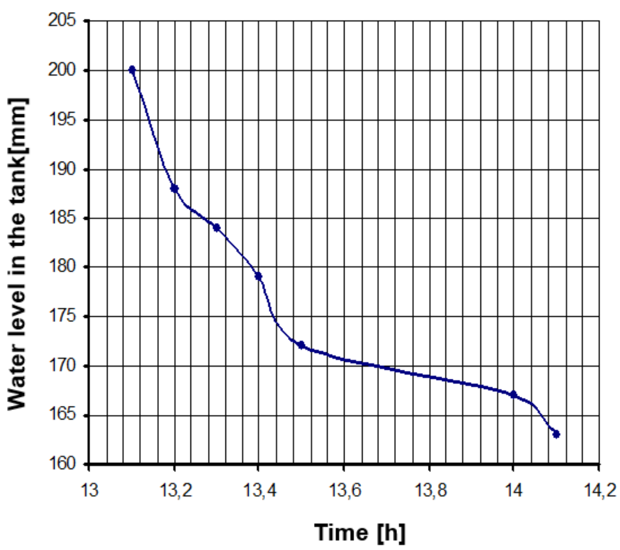

Fig. 4 - Water level variation in the tank depending on time

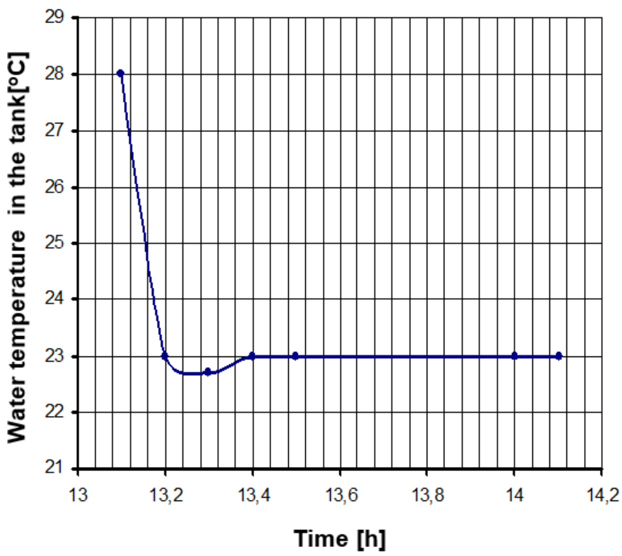

Fig. 5 - Water temperature variation in the tank depending on time

2. C 110P combine cab

In the case of a C 110P combine cab (which, compared to the U-650 tractor cab, also has a roof padding), for outdoor air temperatures of 40-41ºC in the shade, but with a relative humidity of 48-52%, temperatures 21-25ºC were recorded at the device outlet, while at the level of the operator's head 33-35ºC and a relative humidity of 59-63% were measured (Table 3, figures 6-9).

Initial conditions:

- outdoor air temperature, ºC: 40
- outdoor air humidity, %: 48
- temperature in the cab, ºC: 47
- tank water temperature, ºC: 28
- tank water level, mm: 200

Ceiling temperature, ºC: 48
Water consumption resulting from experiments, l/hour: 2.43

Table 3

Results obtained from determinations on the C 110P cab

Environment		Air conditioning					Tank water temperature	Time of determination	Voltage at pump terminals	Water level in the tank
$T_{dry.}$ (°C)	u_{rel} (%)	$t_{dry.cab}$ (°C)	$t_{dry.\ air\ cond.}$ (°C)	$t_{usc.env.} - t_{dry.\ air\ cond.}$ (°C)	v_{air} (m/s)	u_{rel} (%)	(ºC)	(hour:min)	(V)	(mm)
40	48	35	23.2	16.8	16	59	23.0	14:40	18	170
41	48	33	21.2	19.8	16	61	23.0	14:50	18	166
41	48	33	20.8	20.2	16	61	22.8	15:00	18	160
41	48	34	20.7	20.3	16	62	22.6	15:10	16	156
41	48	33	20.7	20.3	16	62	22.6	15:15	24	154
41.5	34	37	24.7	16.8	16	58	23.0	15:20	18	163

Legend:

T_{dry}= outside temperature; u_{rel} = relative humidity;

$t_{dry.cab}$ = temperature inside the cab before using air conditioning;

$t_{dry.\ air\ cond.}$ = temperature using air conditioning system

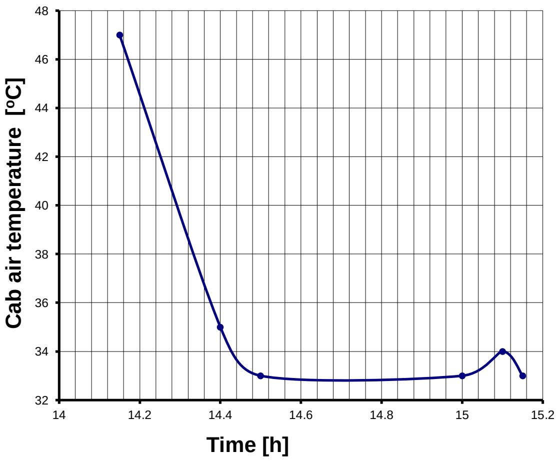

Fig. 6 - Variation of cab air temperature depending on time

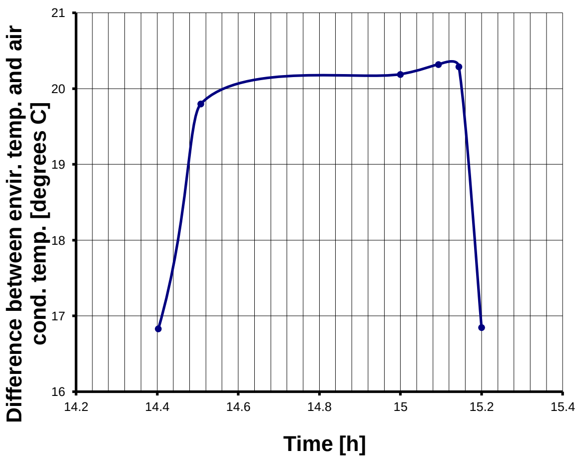

Fig. 7 - Temperature difference generated by the air conditioning system

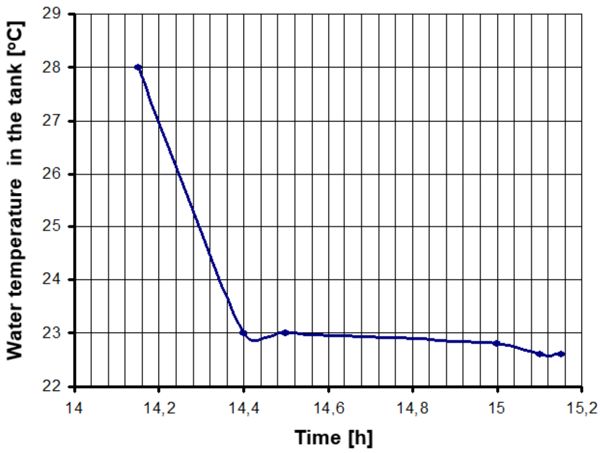

Fig. 8 - Water level variation in the tank depending on time

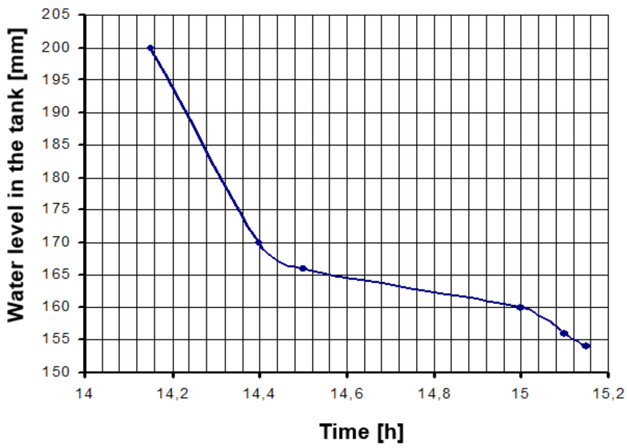

Fig. 9 - Water temperature variation in the tank depending on time

The results obtained demonstrate the efficiency of the created experimental model, but also the need to fit out the cab so as to contribute through the constructive parameters to:

- reducing the level of thermal radiation that enters the cab;
- preventing air currents from entering the interior through areas other than those designed for this purpose (sealing);
- good air circulation at the level of the operator's head, chest and legs, without exceeding the maximum speeds allowed by the domestic and international norms in force.

CONCLUSIONS

As most of the agricultural work is carried out in the warmest period of the year, with temperatures frequently reaching 38°C and even more, it is necessary to equip agricultural machines with air conditioning systems to achieve thermal comfort in the cab.

For this purpose, an air conditioner was designed, made and tested based on the water evaporation process, which has the following advantages over similar freon installations:

- constructive simplicity;
- very low-cost price (1/3 - 1/5 of the price of a refrigeration installation);
- high reliability;
- simple in terms of maintenance and repairs, even performed by non-specialists;
- does not require special marketing licenses as it does not use freons;
- low energy consumption (0.2-0.5 kW);
- quiet during operation;
- non-polluting;
- the large amounts of outside air circulated do not allow the accumulation of particulate matter or pollutants;
- humidification of the air removes the danger of dehydration, which can lead to the appearance of respiratory diseases over time;
- by washing the air (laboratory technique) it removes biological contaminants (pollen, spores, fine dust particles that cannot be retained by ordinary filters, bacteria), gases and smoke (including carbon monoxide in the flue gases), wide variety of chemical vapours (formaldehyde, benzene, toluene, etc.).

Disadvantages include:

- the possibility of achieving lower thermal differences from the external environment than in freon-based installations;
- is dependent on the relative humidity of the ambient air.

In the case of a U-650 tractor cab exposed to solar radiation in conditions of outdoor temperatures of 40°C in the shade, without conditioning or ventilation, 47°C were recorded at the operator's head level (in the cab, the door being open).

The water consumption of the installation was close to the value of 2-3 l/hour, which shows the need to increase the capacity of the water tank for a continuous operation, without refuelling during the working day.

Tank water temperature was 21-23°C, 2-3°C higher than the air conditioning at the outlet of the installation.

The connection between the device and the fan was ensured by means of a flexible aluminium hose with a length of 1.5 m.

Under these conditions, by measuring the temperatures at both ends of the hose, a temperature loss of approximately 3°C was found, having a negative influence on the air parameters in the cab. It is therefore necessary to use a flexible hose made of thermal insulation material (plastic), or the existing one to be thermally insulated.

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