The new steam tunnel of the Belgian Royal Military Academy

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Abstract

A new steam facility was built in the RMA, located in the center of the City of Brussels. In the present article the different objectives to be realized during the design process are highlighted. Also the complete design process and the choice of relevant working parameters are discussed.

1 Objectives

A new steam facility was built in the RMA, located in the center of the City of Brussels. The objectives to be realized are to build a facility that is

1. standing alone and can run for a long period of time in transonic conditions
2. comparable with the previous installation, such that all existing models and instrumentation can still be used
3. fitted in the site of the School and the city.

The general layout of the facility is given in Fig 1. The design process will be discussed for all the components.

2 The steam generator

The design process starts with the steam generator. Hereto the power and the type of fuel must be fixed. The power of the generator is controlled by the mass flow to be delivered, the latter can be calculated since we have to choke the throat section. Since one of the objectives is to be able to use already existing material and testequipment, the width of the test section

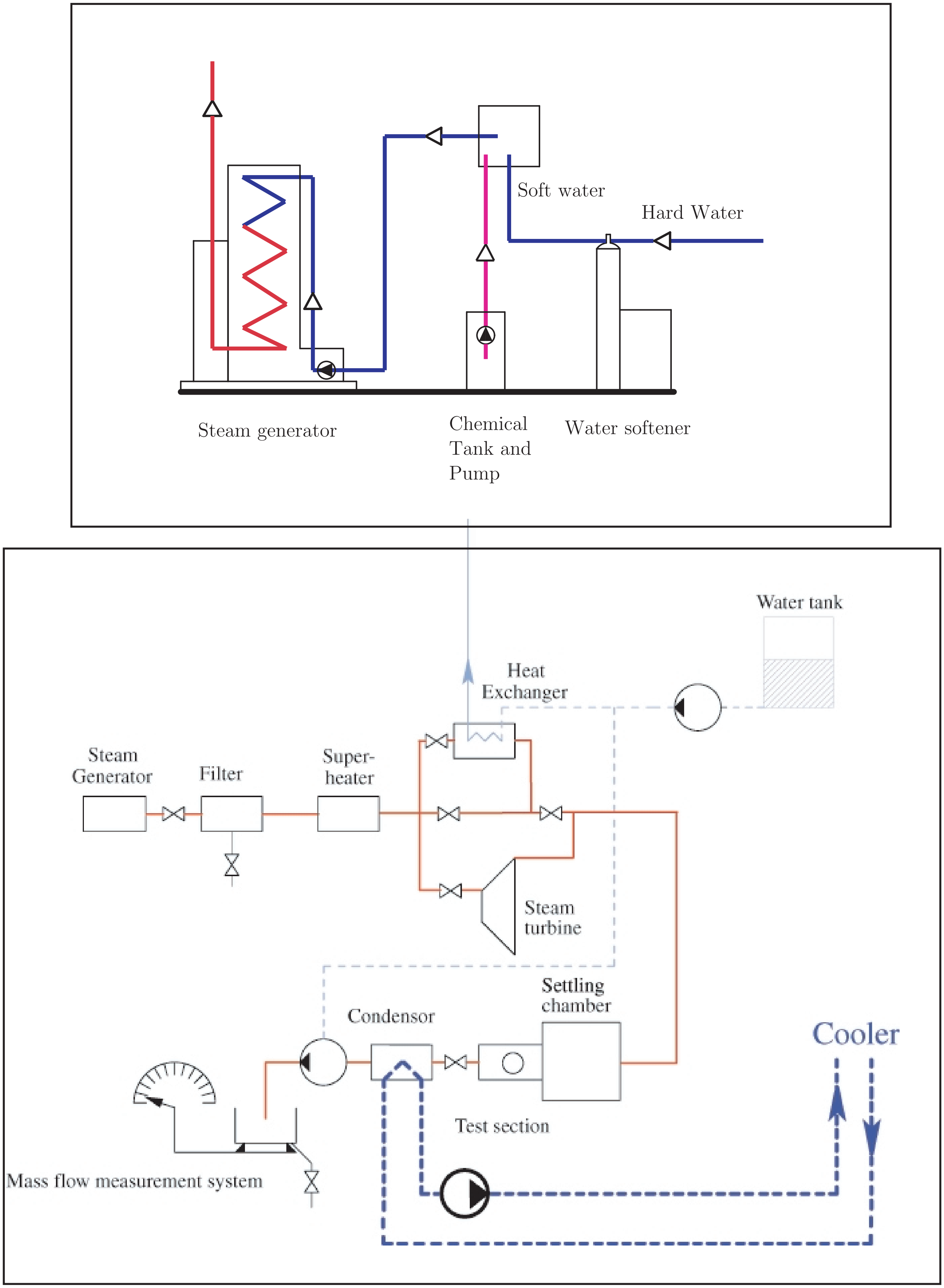

Figure 1: General layout of the steam tunnel

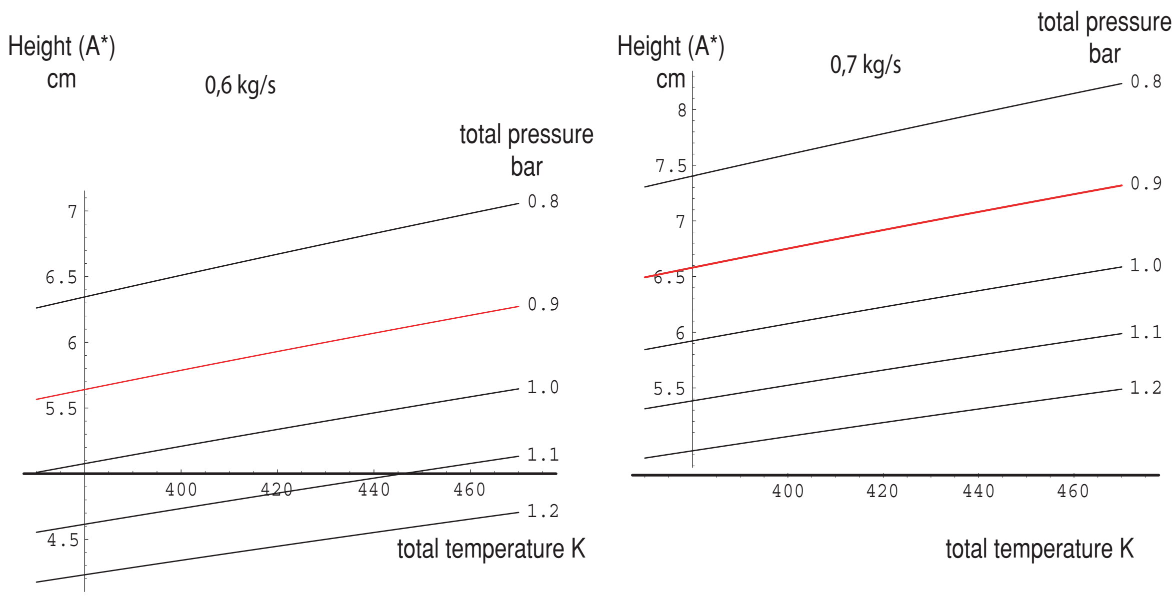

Figure 2: Possible height of the throat section for different mass flows and total thermodynamic conditions

is fixed to be 50 mm: the degree of freedom is therefore the height of the test section or in other words the number of blade passages that can eventually be installed. In Fig 2 different heights are represented for mass flows 0,7 and 0,6 kg/s with varying total conditions. A mass flow of 0,7 kg/s requires roughly a power just above 2 MW, while for 0,6 kg/s this is below 2 MW.

Severe limits are imposed on the composition of the burned gases. Table 1 shows the restrictions for a 2MW and above 2MW steam generator installation fueled with liquid and gas fuel. From the table it is obvious that gas fuel is preferable to the liquid fuel.

The safety regulations and pollution restrictions are such that an installation smaller than 2MW was chosen in order to keep the costs during a run at a reasonable level. The steam generator must be supplied with special treated water: such that water from the city distribution network cannot be used directly (pH between 10,5 and 12, salt concentration < 6000 mg/l, water hardness degree 0, sulfite concentration between 50 and 100 mg/l, water may not contain any visible particles ...). The steam generator chosen has a power of 1,5 MW and delivers steam with a water content of less than 0,5%.

3 The steamcircuit

From the steam generator, steam is led to the laboratory. Downstream a manually operated shut off valve, a safety valve is mounted. (If ever an electrical power cut happens while running the tunnel, the installation could be filled with steam at 10 bar since the cooling has been stopped. This causes serious danger for the people and equipment in the laboratory; therefore a safety valve will open and let the steam escape into a safe corner in the laboratory

Maximum concentration in mg / Nm^3 dry gas			
Pollutant	**Liquid fuel**		**Natural Gas**
	$<$ 2 MW	$<$ 50 MW	$<$ 2 MW
SO_2	350	1700	35
NO_x	250	150	100
CO	175	175	100
Dust	150	150	5

Table 1: Maximum concentration of pollutants in the burned gases of the steam generator

until the main supply valve can be closed.)

The steam is then led to a filter. Since pure water is used in the boiler, this filter can be seen as a water droplet remover. From the filter the steam flows to the super heater where 500 kW can be delivered to the steam. The super heater is electrically powered and therefore can be positioned close to the turbine and test section. From there the steam will go directly to the settling chamber of the steam tunnel or pass via:

1. either a steam turbine where work can be extracted or

2. a heat exchanger to regulate the wetness degree of the steam. This is done by boiling a known chosen mass flow rate of water in atmospheric conditions so that as a result of the conservation of energy, the enthalpy of the steam leaving the heat exchanger can be calculated. This value allows to estimate the wetness degree.

The settling chamber is a rectangular box allowing to install easily different equipment such as turbulence generators, seeding injectors, pressure and temperature sensors.

Downstream the test section a condenser was placed, allowing for the condensation of the steam at 35 °C so that the static pressure in the far downstream plane as seen by the test section equals 5630 Pa, and together with a total pressure in the settle chamber of about 100000 Pa, transonic conditions can obviously be obtained. The 35 °C condenser temperature as seen by the steam, results from the cooling capacity of the cooling water to be discussed in the next section.

4 Steam condensing

The size of the condenser was calculated by fixing the minimal temperature difference between the cooling water and the steam equal to 5 °C : 35 °C -5 °C = 30 °C . Obviously the temperature of the cooling water should be as low as possible. But since ambient air will be used for controlling the temperature of the cooling water, first the temperature evolution of the cooling water will be studied.

The device used for the extraction of heat from the cooling fluid is a forced draught-cooling tower placed on the roof of the building. The air used in the tower is of course ambient air. It is obvious that the tower should be designed for hot (but not extreme) summer conditions. The maximum wet bulb temperature chosen is 22 °C , with a relative humidity of 50% , this corresponds to a dry bulb temperature of 30 °C , which can be considered as an already (very) high temperature in Brussels.

In Fig 3 the layout of the forced draught cooling tower is given. Since heat has to be transferred from the water to the air a temperature difference must be allowed for: a 5 degree temperature difference was chosen. Therefore the water temperature at the exit is (22 °C (wet bulb temperature of the air) plus 5 °C equals 27 °C.The inlet temperature of the water in the tower equals 32 °C since we allow the cooling water to increase 5 degrees in the condenser. Since 2MW power must be dissipated, that is if no work is extracted in the turbine and if no thermal losses occur, the mass flow rate of the cooling water is therefore fixed. (For 2 MW a mass flow of 59 l/s is necessary).

The mass flow rate, the temperature increase of the cooling water and the temperature of the condensed steam allow to determine iteratively the appropriate Re- and Nu-numbers and permit to fix the total cooling surface needed and as such the estimation of the water tubes to be installed in the condenser.

The diameter of the tubes leading the cooling water from the steam tunnel located in the basement of the building to the forced draught cooling tower can be chosen taken into account the maximum velocity that will be allowed because of noise production reasons. Now that the geometry of the cooling circuit has been determined, one can determine the total head to be realized by the pump located in the basement of the building.

Finally the forced draught counterflow cooling tower must be designed: therefore we have to determine the mass flows of the air that is necessary to do the job and the amount of water that will be consumed. Atmospheric air is circulated upward through the cooling tower by a fan located below: a forced draft. The water is fed in the upper part of the tower and falls through a latticework as shown in the Fig 3. As mentioned earlier the temperature of the cooling water at the in- and outlet of the tower were chosen (i.e. the water must be cooled from 32 °C to 27 °C for a 22 °C wet bulb temperature in the ambient atmosphere) and the total power to be dissipated is 2 MW. The amount of coolant air and cooling water evaporation can be calculated. Therefore we assume that at the outlet of the forced draught-cooling tower the air is fully saturated in water vapor (φ = 100%) and the temperature difference between the air and the water is at that place 6 °C , (this temperature difference allows to calculate

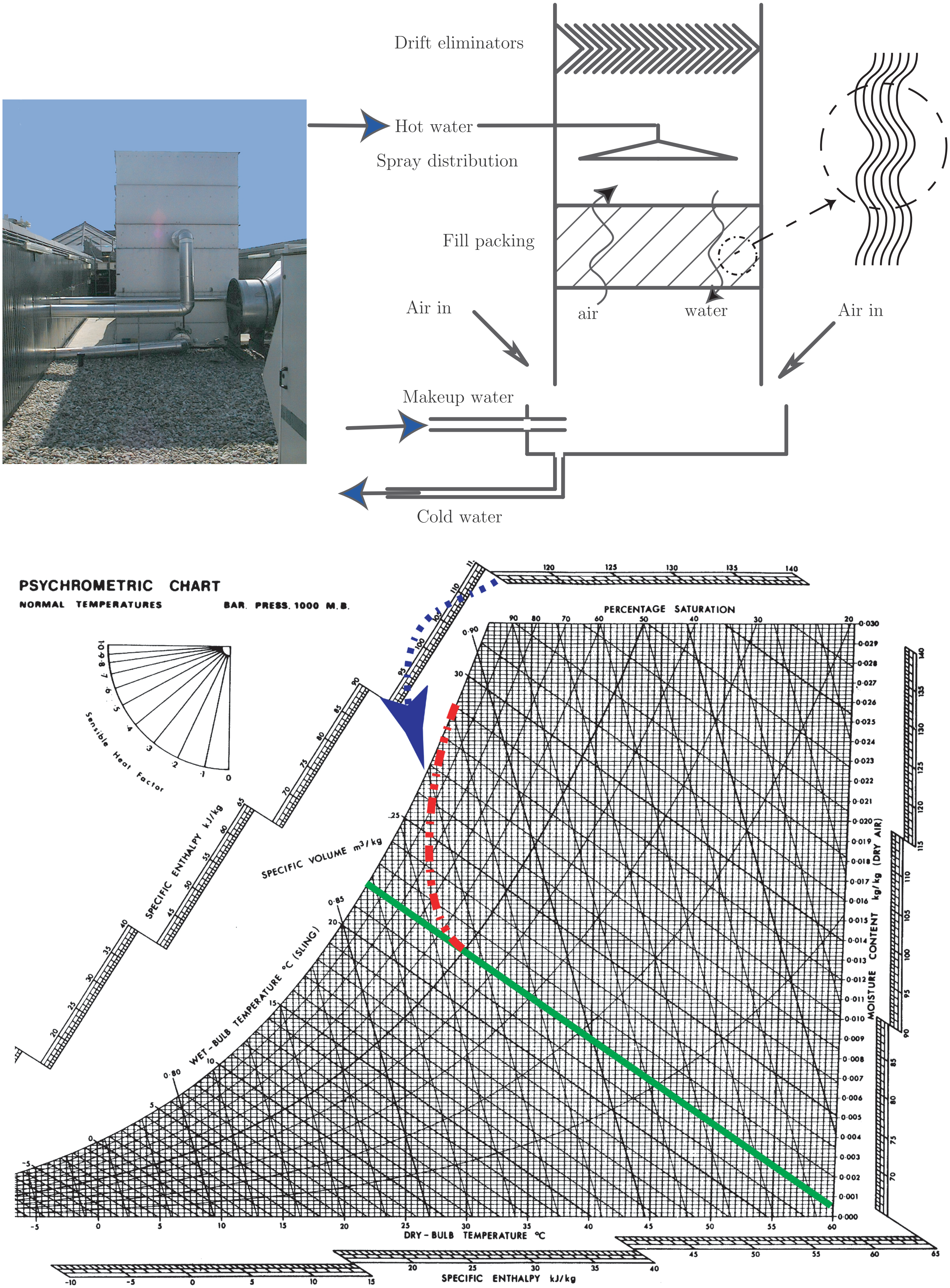

Figure 3: Layout of the forced draught cooling tower

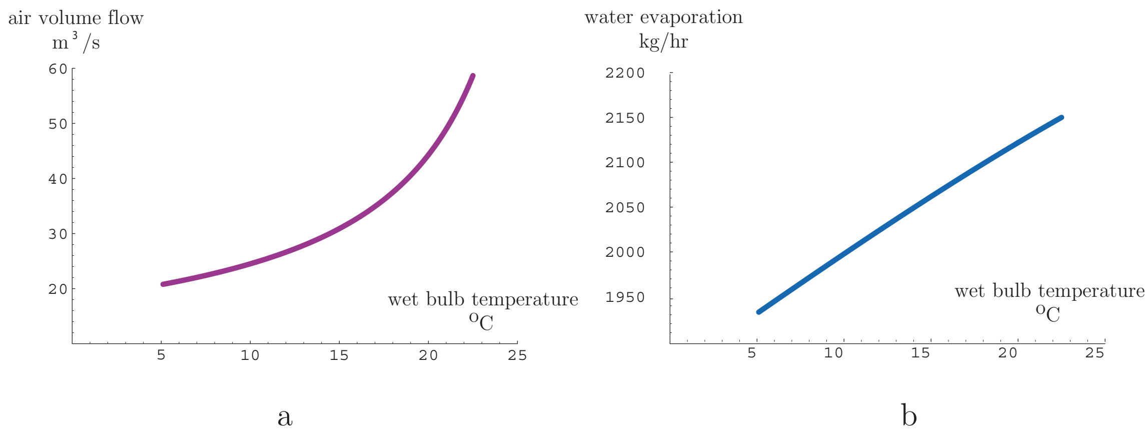

Figure 4: Air and evaporated cooling water mass flows at different ambiant dry bulb temperatures for maximum power settings in the steam generator and the super heater

the log mean temperature different to be 5,2 °C and the design is therefore done with a nearly constant temperature difference in the tower). The air will be saturated in water vapor and warmed up during its journey from the bottom to the top: the necessary time and the necessary contact surface between air and water for this process is obtained by the film type fill packing.

Fig. 4a shows the mass flow rate of cooling air necessary at different outside air temperatures at maximum power delivered to the steam in both the steam generator and superheater. Fig. 4b shows also the amount of cooling water evaporating during the process. This amount must be replaced by fresh water and this is done by keeping the level in the reservoir of the forced draught cooling tower at a constant level. Of course a fraction of the water in the reservoir must be replaced constantly in order to keep the cooling water sufficiently clean (makeup water). Fig 5 shows the mass flow of air and water for different power settings.

Finally the noise generated by the forced draught cooling tower at 3 m distance does not exceed 66 dBA in any direction. At ground level the sound pressure level does not exceed 52 dBA at maximum regime.

5 Conclusions

The design process of the steamtunnel was succesful. In the present effort the logic of the choice of the different components was shown. During the realisation of the tunnel it was verified that all the goals that were imposed are met.

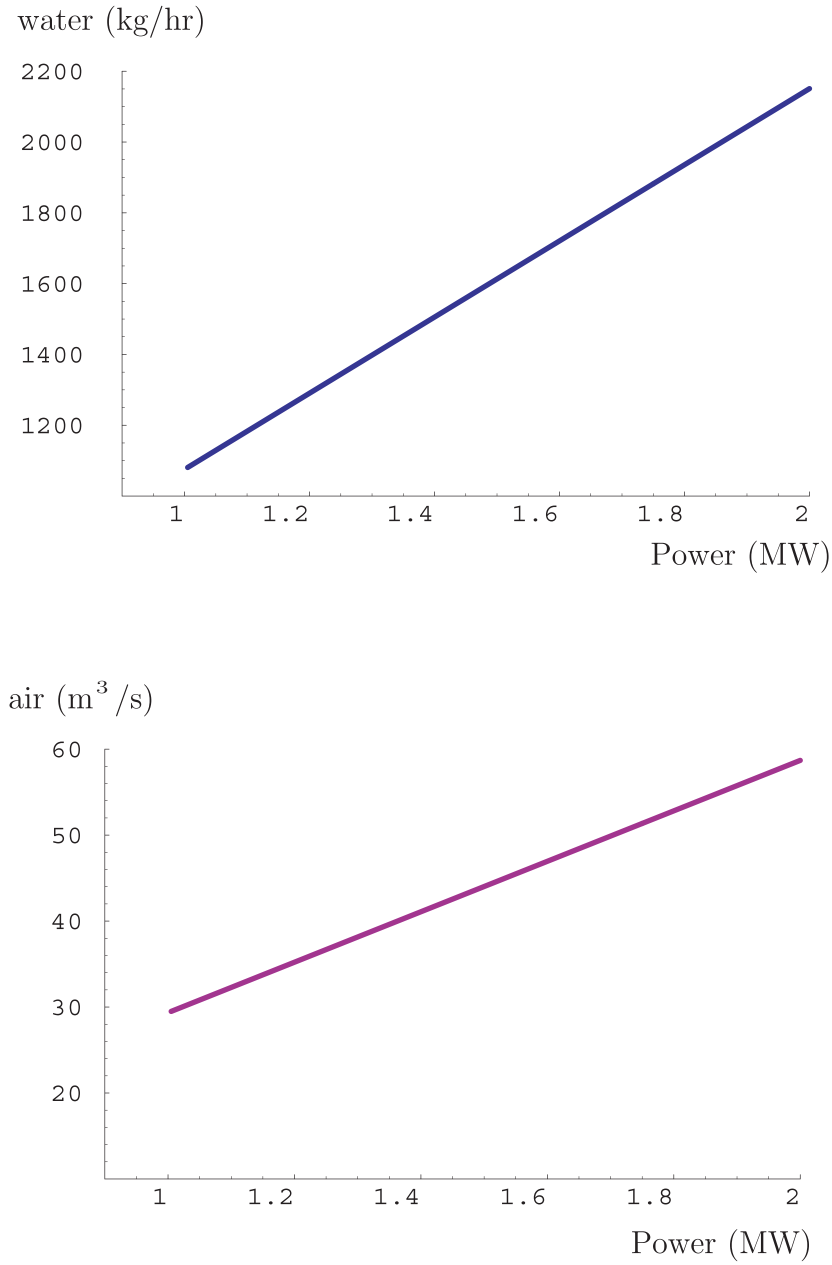

Figure 5: Mass flows at maximum ambiant dry bulb temperature and different power settings