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EXPERIMENTAL STUDY FOR AIR COOLING USING MEMBRANE COVERED TRAY

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ABSTRACT

An experimental study is conducted to cool the outdoor air using a humidification technique. A wind tunnel was built with a membrane covered tray serves as a test section. An outdoor air passes over a tray full of water and covered with a specific membrane. Air temperatures and relative humidity are measured before and after the tray for several air and water speeds. Air speed is measured at different locations along the centerline of the cross section. Results show that as the angle of the tray increases the air temperature drop increases which improve the efficiency of the humidification technique. This enhancement is reflected by a maximum and minimum temperature drop of 7.52 and 2.41^{o}C respectively. Results also show that as the tray angle increases the air relative humidity increases as expected.

INTRODUCTION

The purpose of the present work is to show the use of the evaporation technology in cooling the air before entering the compressor of a gas turbine for improving the output efficiency. A wind tunnel is built and test section consists of an aluminum tray of size 0.30x0.25x0.05 m^3 full of water and covered with a membrane where the atmospheric ambient air passed over it. The tray was fixed inside the test section at different angles. The relative humidity, pressure, air speed and water flow rate are measured before and after the test section. Ali et al. [1] have showed the effect of using ceramic tubes in humidifying the air and lowering its temperature by about 10^{o}C as a maximum based on the ambient temperature using the same test rig used in the current experiment. However, in the current experiment a tray full of water and covered with a specific membrane is studied as a section instead of the ceramic tubes ones. Cooling the air at compressor inlet is a well known technology used to increase the gas turbine capacity and efficiency. Air humidification can be used to cool the air at compressor inlet. This technology is inexpensive, simple to apply and its power consumption is low. Now, the humidification is carried out by spraying water in air flow upstream of the compressor inlet. Using this method requires high quality water to avoid corrosion and erosion of the compressor blades, and scale composition on compressor blades. Furthermore, droplets drift can increase water consumption in humidification process. Membrane evaporation is a new technology used in many applications including desalination, juice concentration, etc. Using this technology in air humidification eliminates blade problems mention above and droplets drift. In addition, low quality water can be used in humidification process. Inlet air cooling markedly enhances the performance of combustion turbines, [2-7]. The turbine power increases at a lower cost per kW than the turbine alone, and as an added bonus the heat rate also improves. Various approaches to cooling the turbine inlet air have been employed. The two most common approaches (evaporative cooling and mechanical refrigeration) have been extensively applied, and are well developed and documented.

Combustion turbines have ambient temperature sensitivity: both the capacity and the efficiency decrease as the ambient temperature increases. The power demand of the compressor section of the turbine is proportional to the absolute temperature of the inlet air. The compressor capacity is proportional to the density of the inlet air, which is inversely proportional to the absolute temperature. Therefore higher ambient temperatures negatively affect both capacity and efficiency of the turbine. The turbine manufacturers supply curves detailing with both the power output and the heat rate as a function of ambient temperature.

The cost of an inlet cooling system is often evaluated in terms of US dollars per KW. A better way of evaluating the economic feasibility of a cooling system is through cost benefit analysis in which the additional revenues are calculated as a result of additional MW hours, fuel savings and gain in the steam production. Erickson et al. [4] reported a 300-refrigeration ton aqua ammonia refrigeration unit is required to cool the inlet of a 5 MW gas turbine from 35°C to 5°C. This cooling increase the power output by 1 MW, and the added power is at a marginal efficiency of 39%, compared to 29% for the base turbine power. Alhazmy and Najar [6] reported that the spray coolers appear to be capable of boosting the power and enhancing the efficiency of the gas turbine power plant in a way that is less expensive than cooling coils. Although the performance of spray coolers is deeply influenced by the ambient temperature and humidity, they operate efficiently during hot and dry climatic conditions. The analysis of [6] have shown that the spray cooler reduces the temperature of incoming air by 3–15 ^{o}C, enhancing the power by 1–7% and improving the efficiency by 3%.

The Membrane evaporation is a new technology which utilized the evaporative cooling technique in air conditioning, water desalination, juice concentration and other applications [8-13]. Microporous hydrophobic membranes have been examined by [8] for possible use as containers in the evaporative cooling of water, particularly in desert climates. An experimental determination was made of the overall heat and mass transfer coefficients of these membranes while surmounting contained water and with air flowing over the surface of the membranes. Similar tests were made with water alone, that is, without a membrane. The coefficients were then used to compare the performance of the existing (canvas water) coolers and membrane evaporative coolers under desert conditions. The performance of the membrane coolers was close enough to that of the canvas coolers that extensive investigation of various aspects of membrane evaporative cooling appears to be justified, particularly in view of the potential advantages of the latter over the existing evaporative cooling methods. For example, for cool storage of perishable goods in a desert climate, the membrane container might be uniquely qualified because of its low rate of water consumption compared to that of a canvas cooler. More recently, a numerical simulation for mass transfer through a porous membrane of parallel straight channels have been reported by Lu and Lu [14]. In their study two types of flows, channel flow and ultra-filtration flow, are physically described. Their results have displayed the flow and solute distribution patterns inside channels, described the ultra-filtration profiles along the surface of the porous membrane and disclosed an existent nano-scale reverse osmosis problem.

EXPERIMENTAL SETUP

The experimental apparatus consists of a wind tunnel and an aluminum tray serves as a test section. The wind tunnel consists of three parts. The first part is the conical part of length 142.5 cm that converts from a circular section of diameter 50.00 cm to rectangular section of 28x14 cm^2 as seen in Fig. 1. This part is attached to a fan of 2.2 kW (1710 RPM) as seen in Fig. For full details of the experimental test rig the reader should consult [1]. The second part is the test section that consists of an aluminum tray of size 0.30x0.25x0.05 m^3 full of water and covered with a membrane as seen in Fig. 2 where the atmospheric ambient air passed over it. The tray was fixed inside the test section at different angles as seen in Fig. 2.

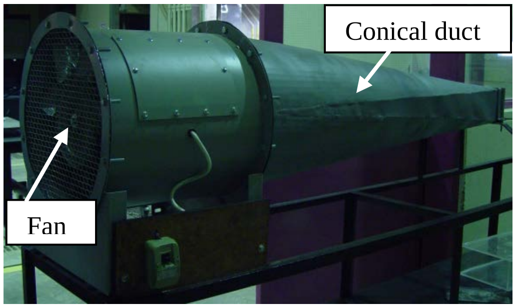


Figure 1. Showing the conical part attached to a 2.2 kW fan.

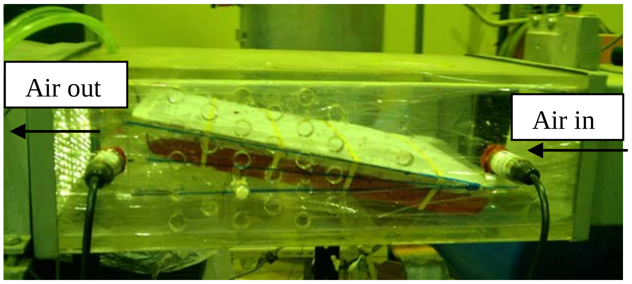


Figure 2. The tray inside the test section covered with the membrane for air cooling by humidification.

The assembled wind tunnel is shown in Fig. 3. The measurement devices such as digital low range water flow meters, velocity and temperature sensors, pressure gages and relative humidity devices are installed on the wind tunnel and connected to the data acquisition system. Relative humidity measuring devices and temperature sensors are installed in their housing on the duct before and after the test section. Variable speed controller is used in the current experiment. Two computers are used; one is connected to the data acquisition system for the air temperature and relative humidity measurements and the other for the air velocity measurements. The air velocity is measured using an 8 channels hot wire anemometer.

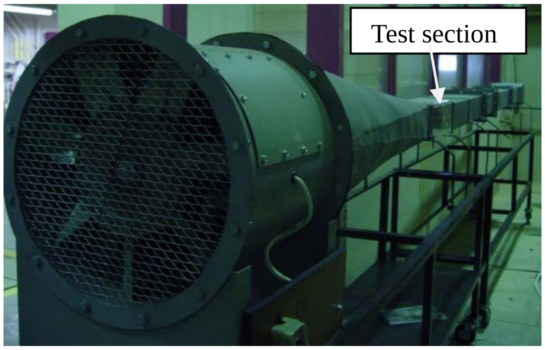


Figure 3. The complete assembled wind tunnel.

EXPERIMENTAL PROCEDURE

Air flow is established using a variable speed motor controller by adjusting the power source frequency which is fed to the fan motor. Air velocity is measured using hot wire anemometers. Seven velocity sensors are fixed on vertical strips, each sensor slides along the vertical direction of the rectangular cross section at distances 7.42, 28.4, 51.24, 70.0, 88.76, 111.58, 132.58, and 140.0 mm to scan the air velocity. The coordinates of the sensors in the x-direction (start from the centerline) are x= 140 mm, 100, 60, 40, 20 and 10 mm respectively before the test section. Following this procedure, air velocities are measured at 48 points. A Data acquisition system is connected to a PC and used to collect the air velocity. Area average air velocity is estimated based on the 48 measured values. Temperature along the air duct is measured using thermocouples and thermistors. K-type thermocouples are distributed along the air duct. Two thermocouples are put at duct inlet to measure the dry and wet bulb temperatures. Two thermocouples are put at the duct exit to measure the dry and wet bulb temperatures. Two thermocouples are fixed before and after the test section to measure the air temperatures across the test section. One thermocouple is used to measure the room temperature. Humidity sensors are used to measure the relative humidity before and after the test section. Humidity sensors also equipped with thermistors to measure temperatures. Two pressure transducers are used to measure the pressure drop across the test section. Two data acquisitions system are connected to a laptop to collect the data of humidity sensors, pressure transducers and thermocouples.

RESULTS AND DISCUSSION

Measurements of the temperature and the relative humidity are taken for a tray full of water and covered with a membrane. The specifications of the membrane are: Celgard (USA) 4560 coated membrane, material pp, laminated thickness 110 µm, and the base film thickness 25 µm. This tray test section was shown in Fig. 2. The results are obtained for three angles of the tray; 0o, 5o, and 10o. Figures 4(a, b, c, and d) show the temperature profiles before and after the horizontal tray (0^o) for four different air velocities of 3.082, 3.392, 3.99, and 4.50 m/s respectively. These figures show that as the air velocity increases the temperature drop between the inlet to and the outlet from the test section decreases. This should not be surprising since the inlet conditions at the test section of temperature and relative humidity are different and the length of the tray is small. These drops in temperature are 7.52, 3.64, 3.94, and 2.41^oC as seen in Figs. 4(a, b, c, d) respectively. These figures show also that the temperature reach the steady state condition in just about 20 minutes. It should be noted that other tray angles give similar results and Fig. 5 summarize the temperature profiles for horizontal and 10 degree tray before and after the test section. This figure shows that as the angle increases the air temperature drop increases which improve the efficiency of the air cooling using this humidification technique.

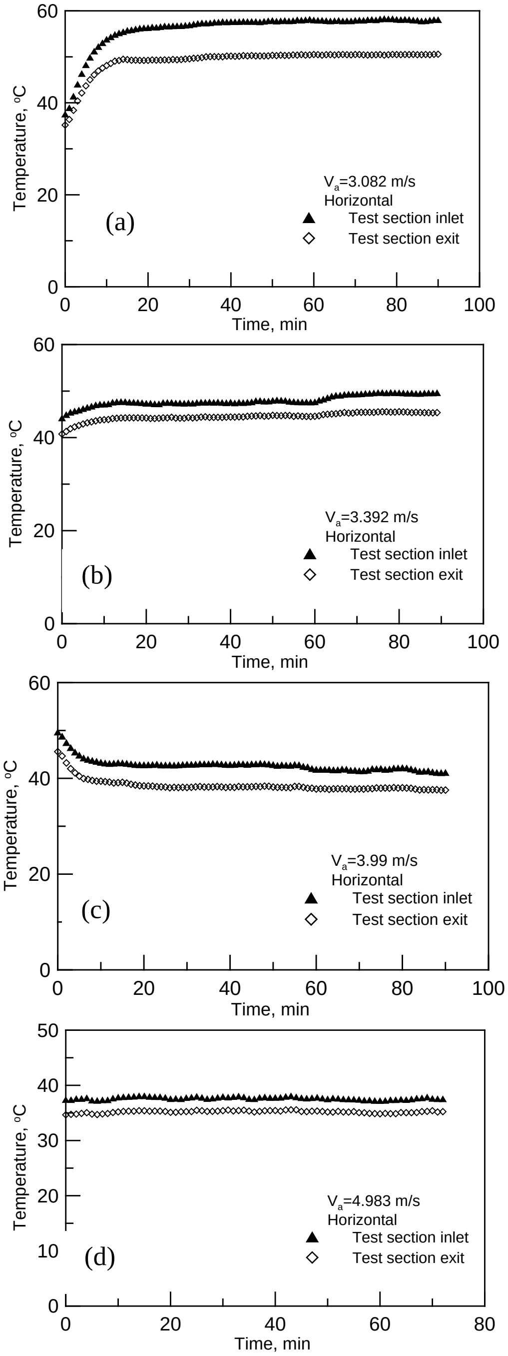


Figure 4. Temperature profiles for different air velocities before and after the horizontal tray test section, (a) v_a = 3.082 m/s, (b) v_a = 3.392, (c) v_a = 3.99, and (d) v_a = 4.983 m/s.

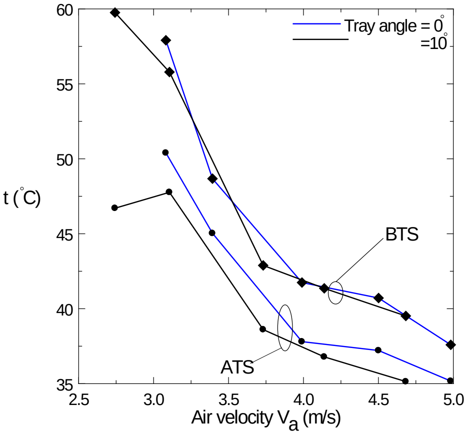
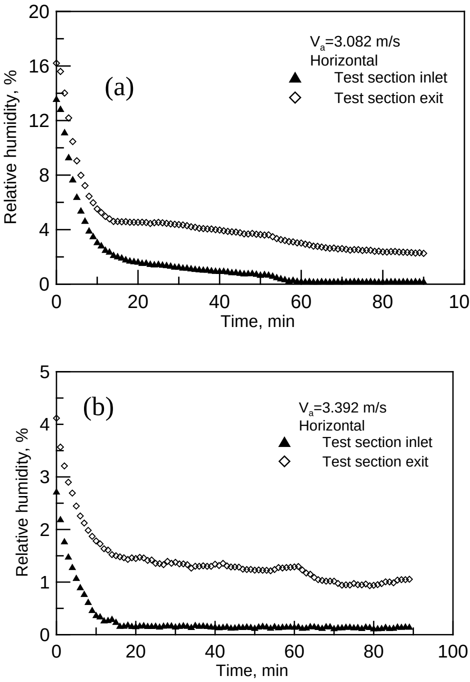


Figure 5. Temperature profiles for different angles of the tray before (BTS) and after (ATS) the test section.

The relative humidity corresponding to the same parameters used in Figs. 4 is shown in Figs. 6 (a, b, c, d) for different air velocity and for horizontal tray. It should be noted that the relative humidity has higher values at the beginning since the temperatures have lower values before they reach steady state as seen in Figs. 4 (a, b). The increase in the average relative humidity before and after the test section is 2.53%, 0.98%, 2.76%, and 2.64% as seen in Figs. 6(a, b, c, d) respectively. It should be mentioned that other tray angles of 5^o and 10^o give similar results for the relative humidity. The profiles for the relative humidity verses the air velocity is shown for two different try angles of 0^o and 10^o in Fig. 7. This figure shows that as the tray angle increases the air relative humidity increases as expected.



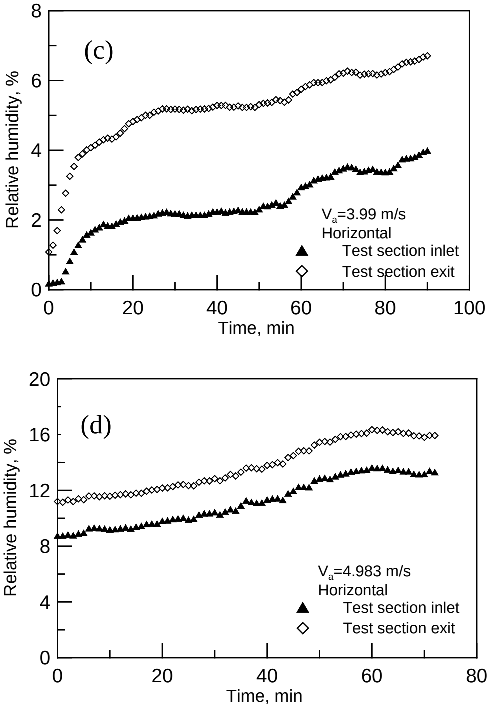


Figure 6. Relative humidity profiles verses time for various air velocities before and after the test section; (a) v_a = 3.082 m/s, (b) v_a = 3.392, (c) v_a = 3.99, and (d) v_a = 4.983 m/s.

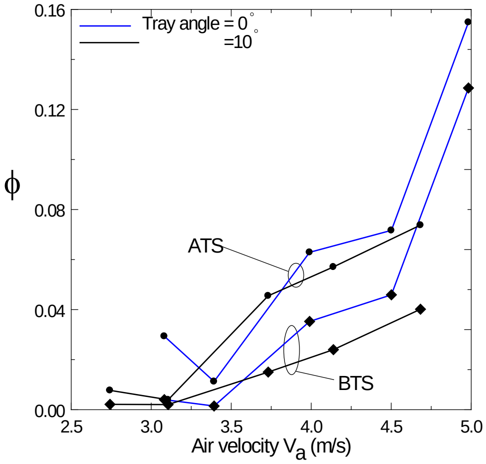


Figure 7. Relative humidity profiles for different angles of the tray before (BTS) and after (ATS) the test section.

Water temperature inside the tray was measured and recorded during the time of the experiment as seen in Fig. 8 for different air speeds. This figure shows that there almost no noticeable changes in the water temperature with the time of the experiment at any fixed air speed. Consequently, all absorbed heat from the air is used as a latent heat for vaporizing the water.

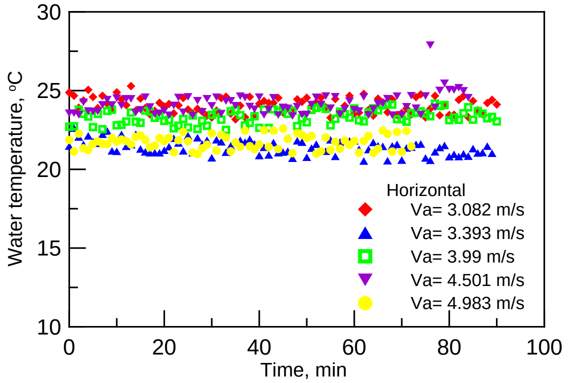


Figure 8. Tray water temperature for various air speeds during the time of the experiment.

CONCLUSIONS

Results show that as the angle of the tray increases the air temperature drop increases which improve the efficiency of the humidification technique. This enhancement is reflected by a maximum and minimum temperature drop of 7.52 and 2.41^{o}C respectively, as seen in Figs. 4. The corresponding maximum and minimum increase in the relative humidity is 2.64% and 0.98% respectively. It is observed that the dissipated heat from the air is used as a latent heat for vaporizing the water with unnoticeable increase of the distilled water. Finally, results show that as the tray angle increases the air relative humidity increases as expected.

ACKNOWLEDGEMENT

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