Humidification–Dehumidification (HDH) Spray Column Direct Contact Condenser
Part I: Countercurrent Flow

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Abstract

Humidification-dehumidification (HDH) is a low grade energy desalination technology. The waste heat from power plant (such NPP) can be used as heat source to preheat water (in evaporator) and air (in condenser). Hot humid air and cooled spray water in counter current flow with direct contact is theoretically analyzing in the present work. Direct contact spray condenser is studied to provide the effect of various parameters on its performance. A computer program describing the theoretical model is designed to solve a one-dimensional differential equations by using Rung-Kutta method. The program predicts the droplet radius, velocity and temperature, besides, the humidity and temperature of air. The results show that, the length of column has great effect on the performance of spray condenser. At column height of 0.762, 2, 5, 10, and 20 m the humidity of the output air decreases by 50, 72, 89, 97, and 99% respectively. The condensate increases about 35% when the length increase from 5 to 10 m at ΔT=15°C while increase only 18% at ΔT=30°C. Also, it is found that, at ΔT=25°C the condensate decrease from H=10 To 5m about 31% and increases from 10 to 20m about32%. While these results for ΔT=15°C are 32% from H=10 To 5m and 36% from 10 to 20m.The increase of both water and air mass fluxes increases the condensate mass flow rate. A case study of a contiguous cogeneration electricity and water in nuclear power plants (NPP), shows that the optimal productivity by HDH is feasible and can reach more than 15 m³/day.m², enabling a total productivity that varied from 120,000 to 300,000 m³/day. The design curves describing the process are obtained together with a formula for the optimal productivity in terms of humid air and sprayed water fluxes at different humid air temperatures is also obtained.

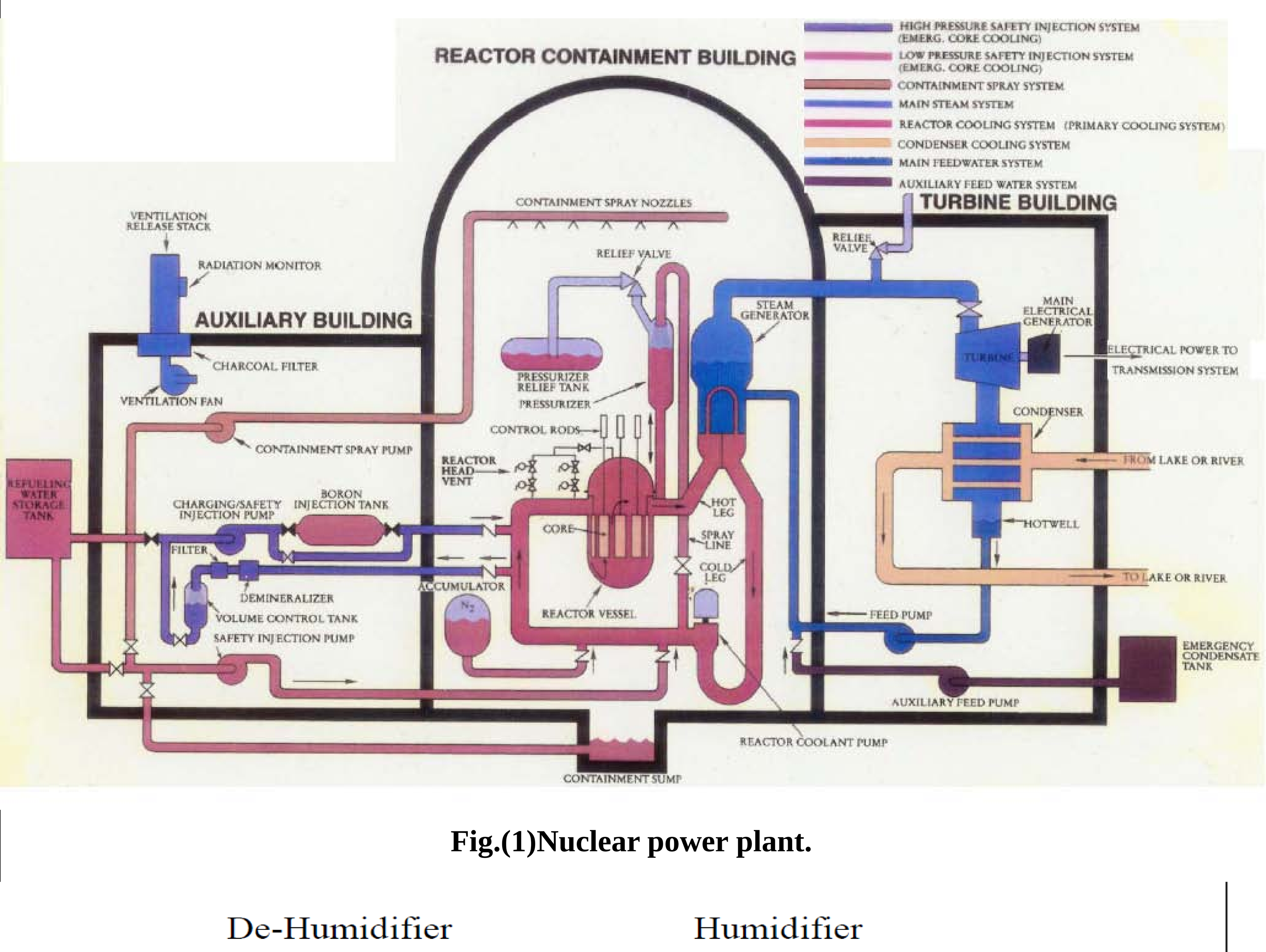

Fig.(1)Nuclear power plant.

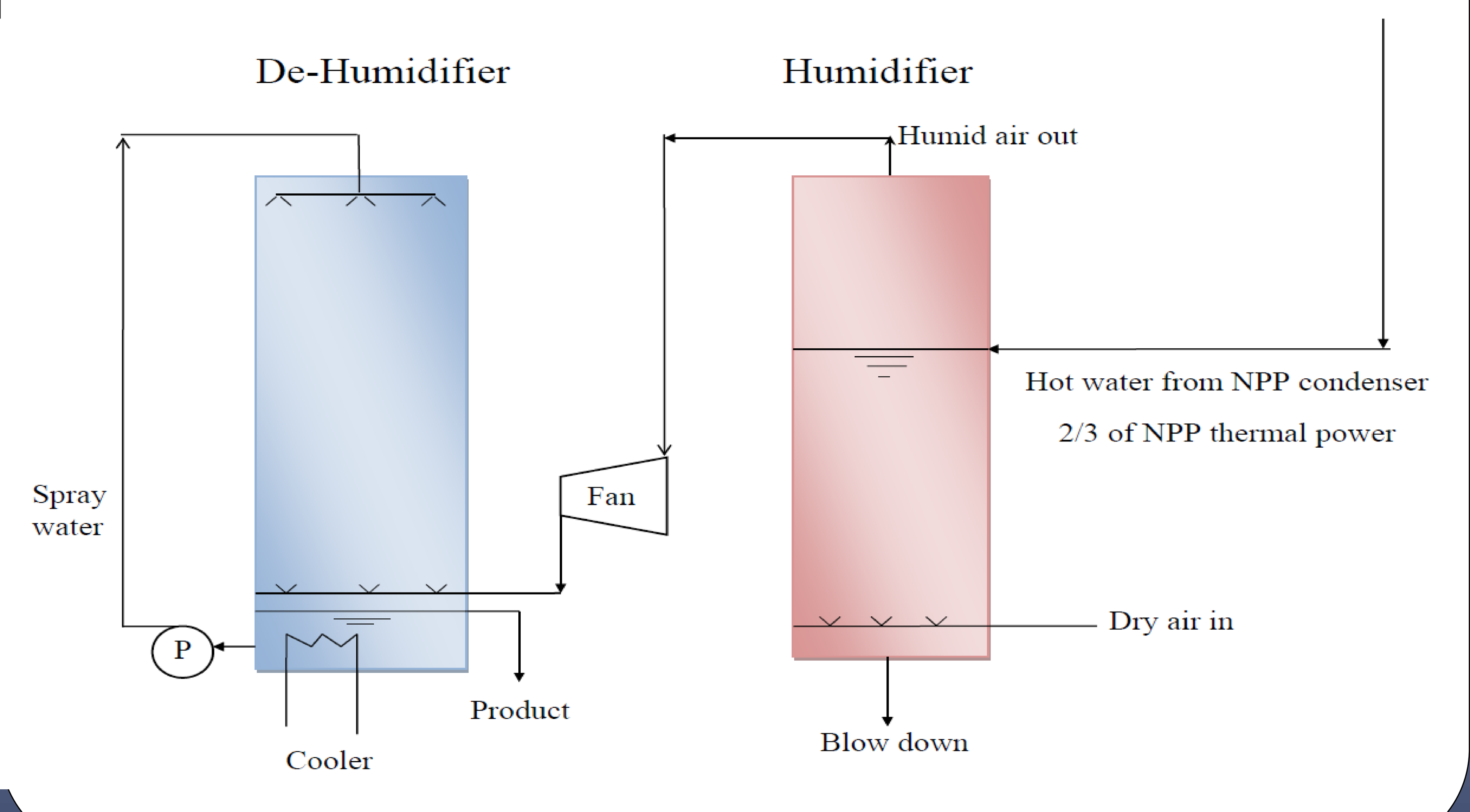

Fig.(2) Flow diagram of HDH unit

Theoretical model

A one-dimensional, quasi-steady mathematical model for a falling droplet in the direct contact condenser (without packing) is presented based on the conservation principles. The following physical assumptions are taken to simplify the model:

1. Droplets are of spherical shape and a uniform droplet distribution.

•No droplet interactions with one another in the axial or transverse direction.

•An average droplet temperature is considered for the quasi-steady state calculations on the droplet side

•Empirical correlations are used for the heat and mass transfer coefficient calculations.

The conservation equations for mass, momentum, and energy of a moving droplet are used to induced the following:

(a)Variation of droplet size-mass transfer
(b) Droplet velocity - momentum transfer
(c) Droplet temperature - energy transfer
(d) Air temperature variation- energy transfer
(e) Mass of condensed vapor

Case Study Results

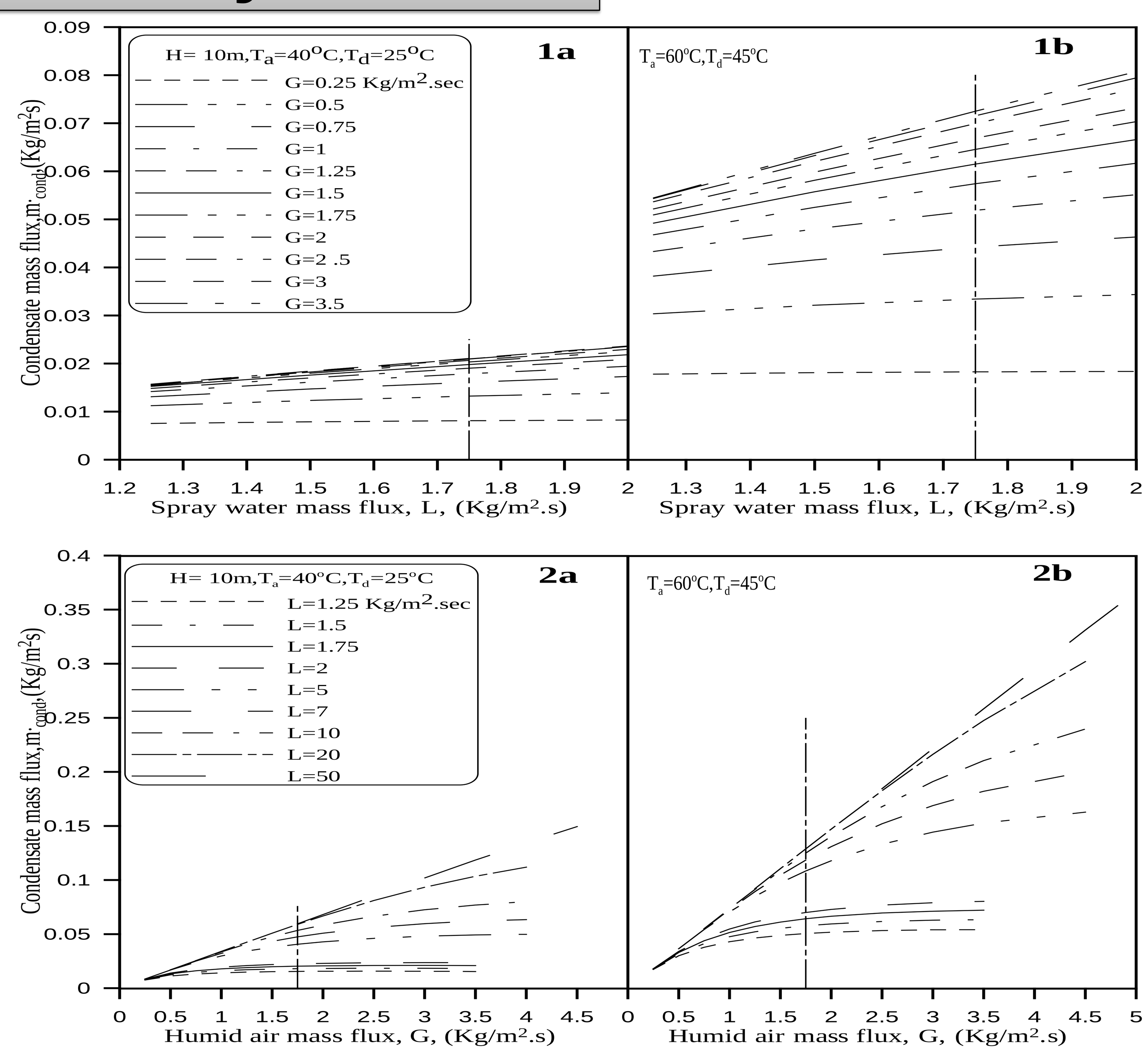

Fig.(3) Variation of the condensate flow rate with the humid air and the spray water mass fluxes at different humid air and droplet temperature.

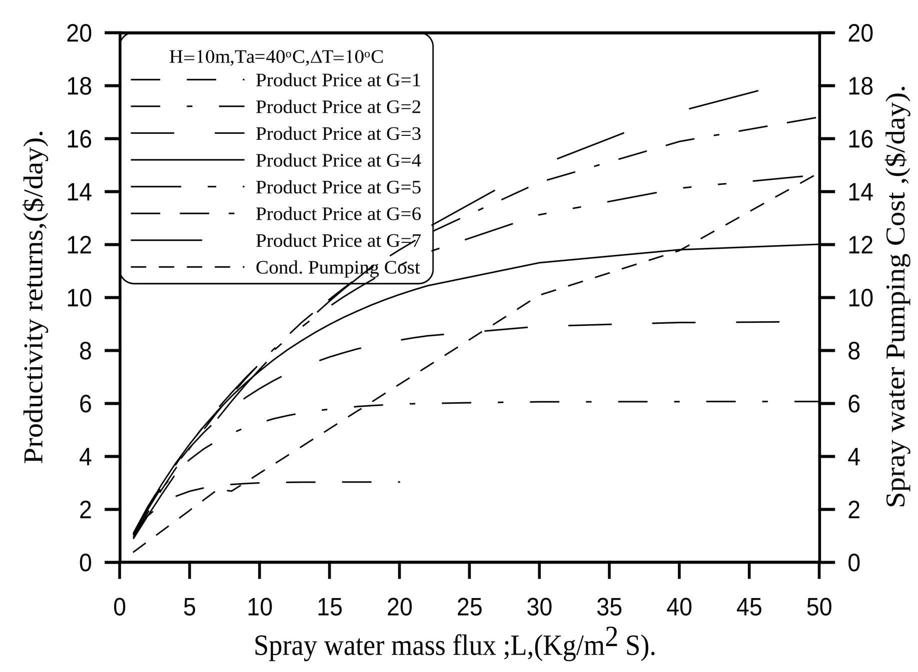

Fig.(4) Effect of spray water mass fluxes on Product returns and pumping costs at different humid air mass fluxes.

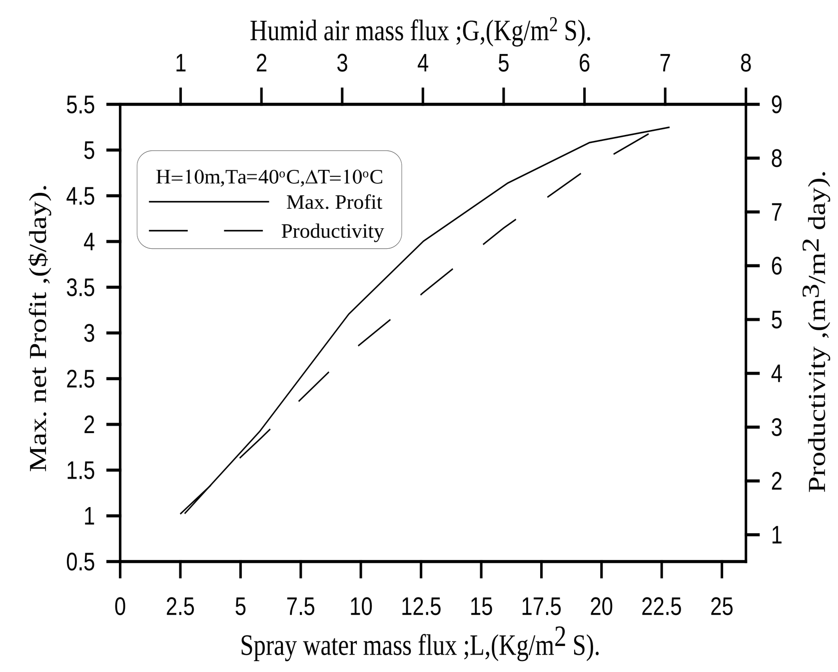

Fig.(5) Variation of the max profit and productivity with the humid air and the spray water mass fluxes.

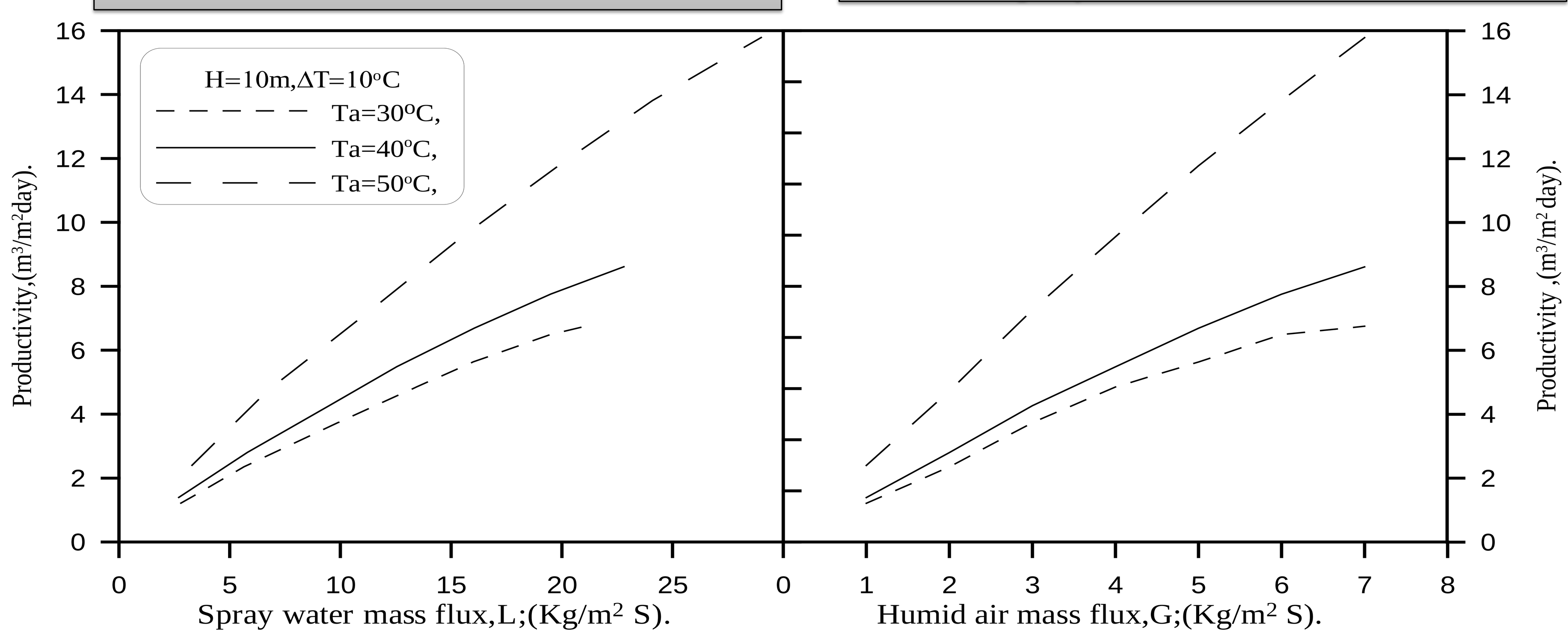

Fig. (6) The variation of optimal productivity with humid air and spray water mass fluxes at different inlet humid air temperature.

Conclusions

1-The productivity at the maximum profit is increased to be about 4.5, 5.2 and 5.6 times with increasing the humid air mass fluxes from 1 to 7 Kg/m²s and spray water mass flux from 2.5 to 22.5 Kg/m²s at the humid air temperature 30, 40,and 50 °C respectively.

2- A case study of a contiguous cogeneration electricity and water in power plants, shows that the optimal water production by HDH is feasible, where the water productivity can reach more than 15 m³/day.m². Large scale of HDH can be feasible to be constructed contiguously with NPP.

3- The design curves describing the process are obtained together with a formula for the optimal productivity in terms of humid air and sprayed water fluxes at different humid air temperatures is also obtained.