

**REVIEW**  
of the official opponent on the thesis of  
Yang Liu  
on the topic “Increasing the efficiency of contact humidifiers in the operating  
conditions of thermal water desalination systems”  
  
submitted for the degree of Doctor of Philosophy  
  
field of knowledge 14 – Electrical Engineering  
Speciality 144 – Thermal Power Engineering

**Relevance of the dissertation topic**

The topic of the dissertation is highly relevant, as it addresses the problem of global freshwater shortages exacerbated by population growth and pollution. This problem is especially important in China. Seawater desalination is a viable solution, especially in coastal and offshore regions. The investigated humidification-dehumidification (HDH) process is a promising method due to its moderate operating conditions and low costs. The dissertation is dedicated to research into the process of air humidification in a film-type contact heat exchanger under typical operating conditions of thermal water desalination systems.

Of particular importance is the development of decentralised small-scale freshwater production solutions, which is especially relevant. Such solutions can be implemented in remote areas with limited access to electricity and fresh water distribution networks. The studied humidification-dehumidification (HDH) process is among the most promising in this context. It has significant advantages, namely: simple construction, operation at atmospheric pressure, an acceptable temperature range, and low investment and operating costs. The results will play an important role in enhancing the HDH system energy efficiency, allowing operation on renewable energy. It facilitates the sustainable development of modern communities worldwide and aligns with priority areas of Ukraine's science development.

**Assessment of the dissertation's scientific results validity, reliability and novelty**

The scientific novelty of the dissertation research results lies in the following:

The author received novel experimental data of the main processes governing air humidification, including hydrodynamics and heat and mass transfer. The results were obtained over a wide range of the main operating parameters of the HDH

system. These data expanded the analysis of the effects of air velocity, water temperature and flow rate on the energy performance of a film humidifier.

The influence of superficial air velocity was studied experimentally, and its limited value was substantiated for the first time. It enables the elimination of transition to the “flooding” regime with droplet contamination of the distillate, while maintaining the high intensity of heat and mass transfer. This limitation allows for minimal pressure losses with stable, efficient operation of the developed film humidifier.

The novel achievement is in the experimental determination of the threshold value for the mass flow rate coefficient, ensuring continuous liquid film flow. It enables smooth operation without abrupt changes in heat and mass transfer intensity, stabilising HDH system performance under the minimal energy requirements.

The model validity was confirmed by using experimental data. Reliability of experimental results is controlled with an analysis of measurement uncertainties using modern statistical methodology.

Therefore, the scientific task set in the dissertation has been fully accomplished, and the applicant has fully mastered the methodology of scientific activity.

### **Assessment of the content of the dissertation, its completeness, and compliance with the principles of academic integrity**

In terms of content, Yang Liu's dissertation fully complies with the Higher Education Standard for speciality 144 – Thermal Power Engineering and research areas in accordance with the Thermal Power Engineering educational program.

The dissertation is a complete scientific work and demonstrates the applicant's personal contribution to the scientific field of developing new processes and equipment for their implementation.

Having reviewed the similarity report based on the results of checking the dissertation for text matches, it can be concluded that Yan Liu's dissertation is the result of the applicant's independent research and does not contain elements of falsification, compilation, fabrication, plagiarism, or borrowing. The ideas, results, and texts of other authors used are properly referenced to the relevant source.

### **Language, style, and structure of presentation**

The dissertation is written in English.

The dissertation consists of an introduction, 5 chapters, conclusions, and a list of references. The total number of pages in the dissertation is 136, with 132 pages for the main part.

The dissertation is written in grammatically correct and stylistically coherent English, corresponding to the standards of scientific and technical literature in the field of engineering. The presentation is distinguished by consistency, clarity, and accessibility. The author demonstrates the ability to formulate complex scientific ideas in a logically structured manner, ensuring smooth transitions between theoretical concepts, experimental design, and interpretation of results. The text avoids redundancy and ambiguity, while maintaining the necessary level of detail to convey experimental findings convincingly.

The chosen writing style is academic and formal, relying on well-established terminology accepted in areas of thermodynamics, heat and mass transfer, and heat transfer engineering. The author consistently uses precise definitions and symbols, which enable an unambiguous understanding of key concepts. The discussion is supported by numerical data, illustrative figures, and tables, all properly referenced within the text. The use of modern scientific vocabulary reflects familiarity with international research discourse.

The structure of the dissertation fully complies with the requirements for doctoral theses in engineering. The Introduction substantiates the relevance of the chosen research topic, identifies the object, subject, goal, and tasks, and outlines the scientific novelty and practical significance. It also specifies the connection of the research with state and institutional programs, ensuring contextual completeness.

The first chapter provides a comprehensive review of literature sources on the designs of contact humidifiers used in thermal water desalination systems. The section begins with an analysis of the problems of freshwater supply in China and the identification of the regions that suffer most from its shortage. It is shown that decentralised small-scale desalination of seawater is a promising solution for coastal areas and offshore islands. The main types of small-scale desalination plants are described. The advantages of HDH systems for use in remote regions are noted, and the limiting factors for their implementation are identified. Considerable attention is paid to the analysis of the designs of contact heat exchangers in HDH systems. The advantages and disadvantages of existing humidifier designs are summarised. A literature review revealed the lack of sufficient data on air and water pressure losses, complicating a comprehensive assessment of the humidifier's efficiency and its energy and exergy indicators. The research presented in this dissertation is aimed at reducing the specific energy consumption of contact humidifiers under typical operating conditions of thermal water desalination systems.

The second chapter describes the experimental installation, designed and manufactured to study the process of air humidification. The installation has an open-air and closed water circuits. The main elements of the installation are a humidifier, a water heater, a pump, a fan, and a system for regulating and measuring

parameters. A transparent acrylic tube 2 m long and with an internal diameter of 26 mm was used as a humidifier. To monitor the temperature and humidity of the air in real time, control and measuring equipment from the company "Regmik" was used. The developed system allows for changing the heat load of the humidifier, regulating the water and air flow rates and carrying out systematic collection of experimental data. It allows for studying the energy characteristics of the humidifier during operation in modes typical of HDH systems. A methodology for conducting experiments has been developed, which includes data collection and processing procedures, as well as the calculation of the heat balance between water and air with the separation of latent and sensible heat parts. An analysis of errors that may occur both in the measurement process and during the calculation of design parameters was carried out.

In Chapter 3, the operating parameters and energy characteristics of a tubular film humidifier are investigated. The classification of water film and air flow regimes in a vertical tube is given, and the mechanism of flooding is described. The absence of clear boundaries of transitions between flow regimes and accurate methods for determining air pressure losses below the flooding point are noted. The flow regimes in the humidifier are visually identified, and the limiting values of water and air mass flow rates at which the transition between regimes occurs are established. It is found that at a superficial air velocity of less than 0.34, pressure losses due to air can be reliably determined using the Darcy–Weisbach formula. It is proposed to limit the superficial air velocity in the humidifier to 0.34, which allows for minimising pressure losses and avoiding contamination of condensate with saltwater droplets. The minimum value of water mass flow rate necessary to maintain continuous film flow is experimentally established. The need to use the minimum ratio of water to air mass flow  $MR = 2$  is substantiated. Under such conditions, maximum efficiency operation of the humidifier is ensured. The influence of the heat supplied to the humidifier on the energy efficiency of its operation is analysed.

In Chapter 4, a thermodynamic model of a film humidifier based on heat and mass transfer equations is developed. The model is validated based on experimental data. New simplified empirical formulas are proposed for determining the heat and mass transfer coefficients in film humidifiers under the operating parameters of HDH systems. A calculation method is developed that can be used for engineering design of film humidifiers, feasibility analysis and optimisation of their operating modes in thermal water desalination systems. The operation of a film humidifier is simulated. The optimal geometric dimensions of a tubular film humidifier are determined: diameter  $d = 50$  mm and height  $l = 1$  m. In addition, the influence of outdoor air parameters on the efficiency of the humidifier is analysed.

In the fifth Chapter, a comparison of the energy performance of the studied film humidifier with other common designs was carried out. Experiments were selected for comparison in which the values of water temperature, air temperature and mass flow rate were approximately the same. A description of various types of packing material, which are widely used in HDH systems, is given. The operating parameters and energy characteristics of the humidifiers selected for comparison are presented. The influence of the ratio of water and air mass flow rates (MR) on the evaporation intensity, thermodynamic efficiency and aerodynamic air resistance is analysed. The advantages of the film humidifier compared to packing materials, bubble columns and atypical designs are determined. It is demonstrated that the film humidifier provides the highest evaporation intensity among all types of humidifiers. At the same time, its aerodynamic and hydraulic resistance is minimal. It has been established that the use of a film humidifier allows for reducing the consumption of electricity required for the circulation of water and air in the HDH system without degrading its performance.

The Conclusions summarise the achieved results and demonstrate their correspondence to the initial aims. They are formulated clearly and reflect both theoretical significance and practical applicability.

Throughout the dissertation, the language remains clear and precise. Each chapter begins with a brief introduction and ends with intermediate conclusions, ensuring a coherent flow of information. Literature references are accurate and formatted in accordance with academic requirements. The structure of the text, the clarity of reasoning, and the consistency of terminology contribute to high readability and comprehension of the research.

The dissertation is formatted in accordance with the requirements of Order No. 40 of the Ministry of Education and Science of Ukraine dated January 12, 2017, “On Approval of Requirements for Formatting Dissertations”.

### **Presentation of dissertation results**

The scientific results of the dissertation are presented in 6 scientific publications by the applicant, including: 2 articles in scientific journals included in the list of scientific professional publications of Ukraine at the date of publication; 3 articles in Presiding of the conferences; 1 article in periodical scientific journal indexed in the Web of Science Core Collection and Scopus databases, which is in publications classified as second quartile (Q2) according to the SCImago Journal and Country Rank or Journal Citation Reports classification. The results of the dissertation are also tested at 3 scientific conferences.

The applicant's publications are distinguished by their high scientific quality, are relevant to the topic of the dissertation, and are at the current level of

development in the field. The works comply with all requirements of academic integrity, and no cases of plagiarism or incorrect citation have been found. The applicant's contribution to joint publications is significant and clearly defined.

Thus, the scientific results described in the dissertation are fully covered in the applicant's scientific publications.

### **Shortcomings and comments on the dissertation**

1. On page 3. “Regmik” should be corrected to “company Regmik” for clarity.
2. On page 3. Stated “It was found that at a superficial air velocity below 0.34 m/s, ...”. What are the units of superficial air velocity?
3. On page 4. Sentence “The advantages of the film humidifier over packing materials, bubble columns, and non-standard designs were identified.” Needs correction.
4. The number of keywords in the English text is 7, but in the Ukrainian text it is 17. Check consistency.
5. In the literature survey, an important paper on the subject of Ukrainian scientists is missing: Solomakha, A., Barabash, P., & Rifert, V. (2024). Experimental investigation of mass transfer characteristics in centrifugal humidifier. Thermal Science and Engineering Progress, 53, 102769. The comparison with such a construction is required.
6. On page 14. “f – frictional factor” needs correction to “f – Darcy friction factor”.
7. On page 51. Lump references are not informative for the reader; at least some words must be mentioned for each. E.g. [50, 52, 53, 56, 64], [48, 54, 55, 60, 61, 63, 65] etc.
8. On page 55. What was the thickness of the tube wall? How is it influencing the process?
9. In Table 2.1. The uncertainty (not Accuracy) must be given. What was its confidence level? Better not to use the word accuracy in this context.
10. On page 72, check and correct “abo”.
11. On page 79. What is the share of the hydrostatic pressure difference that allows for neglect? Especially in the case of flooding.
12. Page 83. “This is because the disruption of a continuous falling film reduces the intensity of the heat and mass transfer process in the tube.” But how does the increase in surface and film turbulence affect?
13. Page 85. “at a constant (optimal) air velocity and water flow rate,” what was the objective function in choosing optimal parameters?
14. On page 92. G must be explained in the Nomenclature.

15. Figure 5.6. Caption needs correction. An error message appears.

I consider the comments not decisive and do not diminish the overall scientific novelty and practical significance of the results, nor do they affect the positive assessment of the dissertation.

### **Conclusion of the dissertation**

I consider that the doctoral dissertation of Yang Liu on the topic “Increasing the efficiency of contact humidifiers in the operating conditions of thermal water desalination systems” has been completed at a high scientific level, does not violate the principles of academic integrity, and is a complete scientific study, the combination of theoretical and practical results of which solves a scientific problem that is of significant importance for the field of knowledge 14 – Electrical Engineering. In terms of relevance, practical value, and scientific novelty, the dissertation fully complies with the requirements of the current legislation of Ukraine, as provided for in paragraphs 6–9 of the "Procedure for awarding the degree of Doctor of Philosophy and revoking the decision of a one-time specialized academic council of a higher education institution, scientific institution on awarding the degree of Doctor of Philosophy," approved by Resolution of the Cabinet of Ministers of Ukraine No. 44 of January 12, 2022.

The applicant Yang Liu deserves to be awarded the degree of Doctor of Philosophy in the field of knowledge 14 –Electrical Engineering, speciality 144 – Thermal Power Engineering.

### **Official opponent:**

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of Integrated Technologies,  
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Petro KAPUSTENKO