Investigation of the Influence of the Computational Grid for Turbulent Flow

Murodil Erkinjon Ugli Madaliev, Rustam Ismailovich Maksudov, Ikrom Isroiljonovich Mullaev, Bahram Khaliljonovich Abdullaev, Azizbek Rozikboevich Haidarov

Ferghana Polytechnic Institute, Ferghana, Uzbekistan

ABSTRACT

The article provides basic information about the principles of calculations based on the solution of the system of Navier-Stokes equations by the control volume method, and the relationship between velocities and pressure was found using the SIMPLE procedure. For the numerical solution of this problem, schemes against the flow of A.A. Samarsky and McCormack were applied. The results were compared with each other and with experimental data. The Spalart-Allmares model is used for turbulence. On the example of a two-dimensional flow model in a straight channel, the influence of the quality of the grid and turbulence models on the distribution of flow parameters inside the calculated zone and the integral characteristics of the flow is studied.

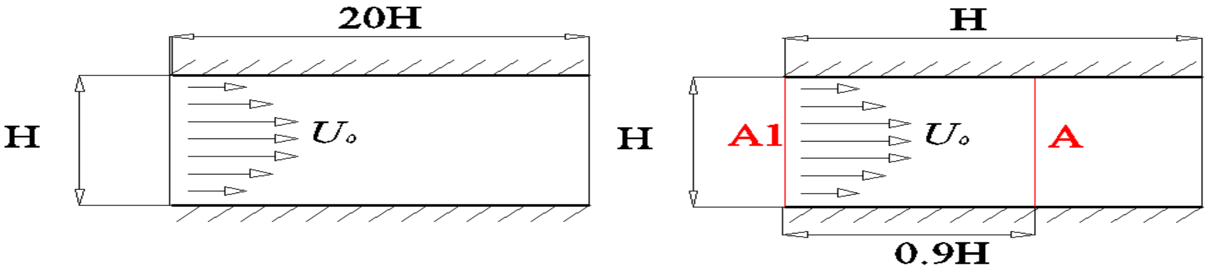
KEYWORDS: *Navier-Stokes equations, SIMPLE, McCormack, control volume method.*

1. Introduction

Mathematical modeling, as one of the ways to gain new knowledge, is today one of the main research methods in various fields of natural science. The movement of gas in a wind tunnel, the propagation of tsunami waves, the spread of plasma in a trap, weather changes and other numerous phenomena in science and technology are described by various mathematical models presented in the form of integral or partial differential equations. Modern computational algorithms make it possible to solve these systems of equations with sufficient accuracy in two-dimensional and three-dimensional approximations when solving various classes of problems, taking into account real geometries and the unsteadiness of the process. Further progress in the development of numerical methods is associated with the development of new numerical algorithms and the growth of the speed and power of modern computer technology [1]. Modern numerical methods accelerate the process of developing new products, allow you to point out the weaknesses of existing ones, but the question arises about the reliability of the results obtained. The accuracy of the results obtained using these calculations depends on the choice of turbulence models, as well as on the number of elements of the computational grid. The purpose of this work is to study the influence of numerical schemes on the results of calculations and their agreement with experimental data, to determine the degree of influence of various grid parameters on the resulting flow structure [2].

2. Physical and mathematical formulation of the problem.

A two-dimensional turbulent flow in a flat channel is considered. To get a developed turbulent profile, there are two ways: 1) to use a long channel, the length of the channel should be 20 times its height. This requires additional calculation time. And there is a second method 2) Called the boundary condition of copying Spalart and Leonard [3], Lund et al. [4] we take a short channel and copy its values at the output to the values at the input $A1(U,V,p)=A(U,V,p)$. In this article, it is investigated for both cases. The physical picture of the analyzed flow and the configuration of the computational domain are shown in Fig. 1.



a) б)

Fig. 1. Diagram of the computational domain in a flat channel a) the first case, b) the second case

The system of unsteady Navier-Stokes equations averaged by Reynolds after using the Businesque hypothesis and the continuity equation with constant density $\rho = const$ in Cartesian coordinates has the following form [5]:

$$\begin{cases} \dfrac{dU}{dt} + \dfrac{\partial p}{\rho \partial x} = \dfrac{\partial}{\partial y}\left((\nu + \tilde{\nu}) \dfrac{\partial U}{\partial y} \right) + \dfrac{\partial}{\partial x}\left((\nu + \tilde{\nu}) \dfrac{\partial U}{\partial x} \right), \\ \dfrac{dV}{dt} + \dfrac{\partial p}{\rho \partial y} = \dfrac{\partial}{\partial y}\left((\nu + \tilde{\nu}) \dfrac{\partial V}{\partial y} \right) + \dfrac{\partial}{\partial x}\left((\nu + \tilde{\nu}) \dfrac{\partial V}{\partial x} \right), \\ \dfrac{d\tilde{\nu}}{dt} = \mathrm{Pv} - \mathrm{D\,v} + \dfrac{1}{\sigma}\left[\dfrac{\partial}{\partial y}\left((\nu + \tilde{\nu}) \dfrac{\partial \tilde{\nu}}{\partial y} \right) + \dfrac{\partial}{\partial x}\left((\nu + \tilde{\nu}) \dfrac{\partial \tilde{\nu}}{\partial x} \right) \right] + \dfrac{C_{b2}}{\sigma}\left(\left(\dfrac{\partial \tilde{\nu}}{\partial x} \right)^2 + \left(\dfrac{\partial \tilde{\nu}}{\partial y} \right)^2 \right), \\ \mathrm{Pv} = C_{b1}(1 - f_{t2})\tilde{S}\tilde{\nu}, \ \ \mathrm{Dv} = \left[C_{w1} f_w - \dfrac{C_{b1}}{k^2} f_{t2} \right] \left(\dfrac{\tilde{\nu}}{d} \right)^2 . \end{cases} \quad (1)$$

Here are, U, V respectively, the longitudinal and vertical components of the flow velocity vector, p is the hydrostatic pressure, and $\mathrm{Re} = HU_0 / \nu$ is the Reynolds number. $\tilde{\nu}$ - linear vortex viscosity and turbulent vortex viscosity is calculated by the formula: $\nu_t = \tilde{\nu} f_{v1}$. The remaining values remain the same as for the "standard" model, which are presented in [6]. All fixed solid walls have obvious boundary conditions of adhesion $U|_\Gamma = 0$ and $V|_\Gamma = 0$, where Γ is a solid boundary.

3. Solution method

For the numerical solution of the system of initial nonstationary equations (1) for all schemes, the finite difference method is used. Due to the difficulties of matching the velocity and pressure fields, a grid with a spaced structure of the arrangement of grid nodes for dependent variables was used to discretize the equations of motion in X, Y directions and the continuity equation. This means that the velocity and pressure components are determined at different nodes. This approach is similar to the SIMPLE methods and gives certain advantages when calculating the pressure field [7-9]. The layout of cells and nodes is similar to the scheme of the SIMPLE method.

3.1. Numerical schemes

Scheme upwind

A flow - versus - flow approximation scheme of the second order of accuracy for derivatives in space and of the first order in time $O(\Delta t, \Delta x^2, \Delta y^2)$, stable at $\frac{\Delta t}{\min(\Delta x, \Delta y)} \le 1$. In this case, the diffusion terms are approximated according to the scheme with central differences of the second order, and for convective terms, the second order is approximated according to the scheme against the flow and the first order of accuracy in time [10].

McCormack Scheme

The McCormack method is widely used to solve equations of gas dynamics. McCormack is especially convenient for solving nonlinear partial differential equations. Applying an explicit predictor-corrector method to the nonlinear Navier-Stokes equation. This is an explicit second-order $O\left((\Delta t)^2, (\Delta x)^2, (\Delta y)^2\right)$ accuracy scheme with an approximation error, stable at $\frac{\Delta t}{\min(\Delta x, \Delta y)} \le 1$ [11].

3.2. Calculated Grids

In computational fluid dynamics, it is extremely important that the simulation correctly represents the conceptual model. Moreover, the simulation should resemble real flows as accurately as possible. Numerical modeling has various advantages over experiments [12]. The main one is that the parameters can be easily changed and quick results are possible at a lower cost. In this study, three samples of the calculated grid were used. Which mesh is crushed at the walls of the channel Fig. 2.

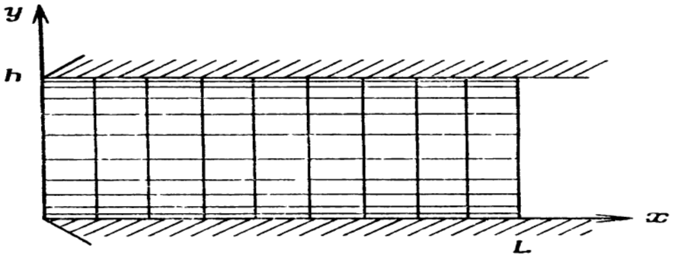


Fig. 2. Shredding the mesh at the channel wall

Grinding is given with a wave of the following formulas.

$$y = h\frac{(\beta+2\alpha)\left[(\beta+1)/(\beta-1)\right]^{(\bar{y}-\alpha)/(1-\alpha)} - \beta + 2\alpha}{(2\alpha+1)\left\{1+\left[(\beta+1)/(\beta-1)\right]^{(\bar{y}-\alpha)/(1-\alpha)}\right\}}.$$

If $\alpha = 0$, then the mesh will be crushed only near $y = h$ whereas if $\alpha = 1/2$, then the mesh will be crushed both near $y = 0$ and near $y = h$. Roberts showed [2, 13] that the stretching parameter β is approximately related to the dimensionless thickness of the boundary layer δ / h as follows:

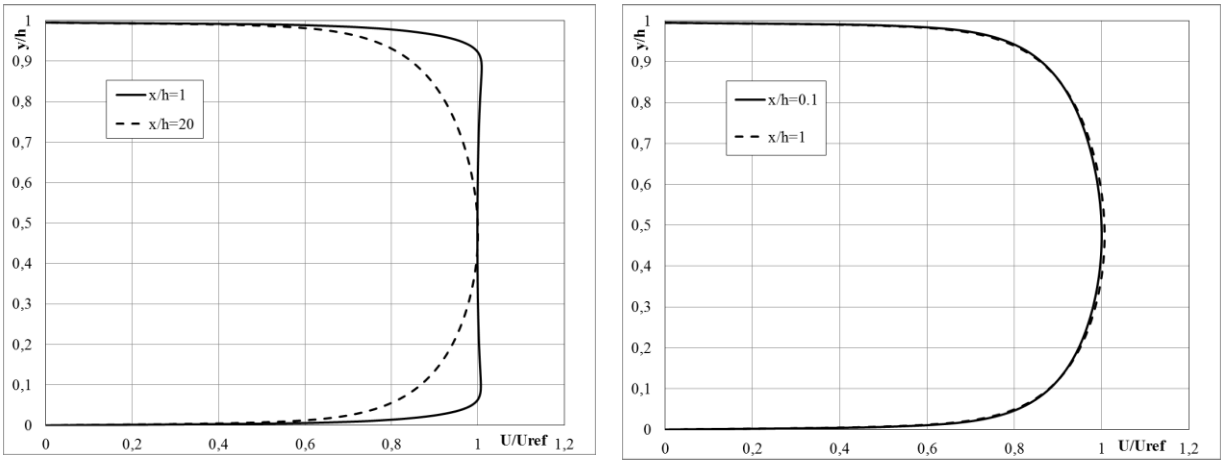
$$\beta = (1 - \delta / h)^{-1/2}, \; 0 < \delta / h < 1.$$

где h — размер сетки в направлении y. Число сетки для первый случи использовано, 1000×100 а для второй случи 100×100.

4. Calculation results and their discussion

This work pursued two main goals. The first consisted in testing a numerical technique for integrating two-dimensional unsteady Navier-Stokes equations in velocity-pressure variables using a well-known finite-difference scheme. The second is to study the influence of the calculated grid on the results of the study.

Fig. 3 shows the results of the longitudinal velocity using two types of channel. Reynolds number $\mathrm{Re} = 36000$.



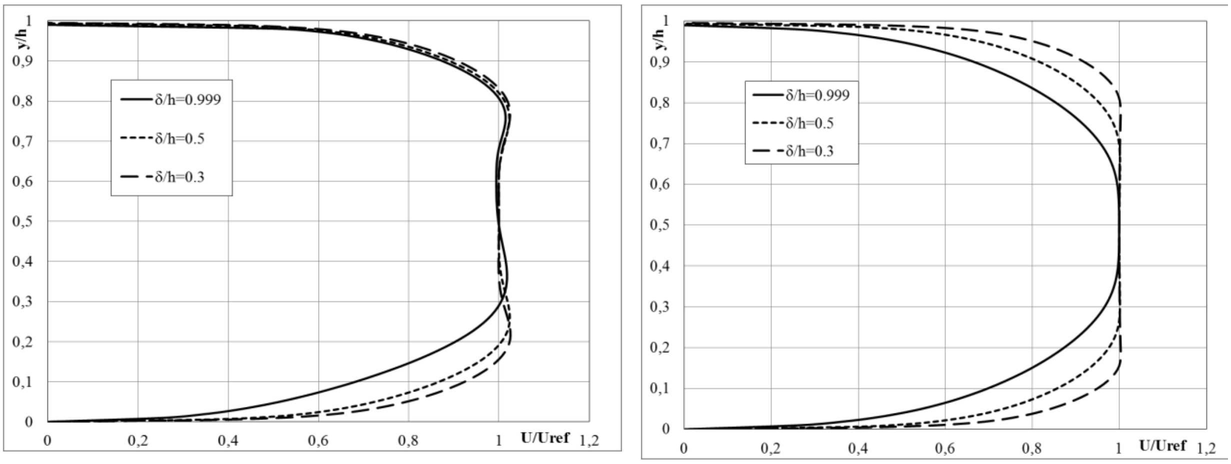
a) b)

Fig. 3. Longitudinal velocity using two types of channel a) long channel, b) short channel.

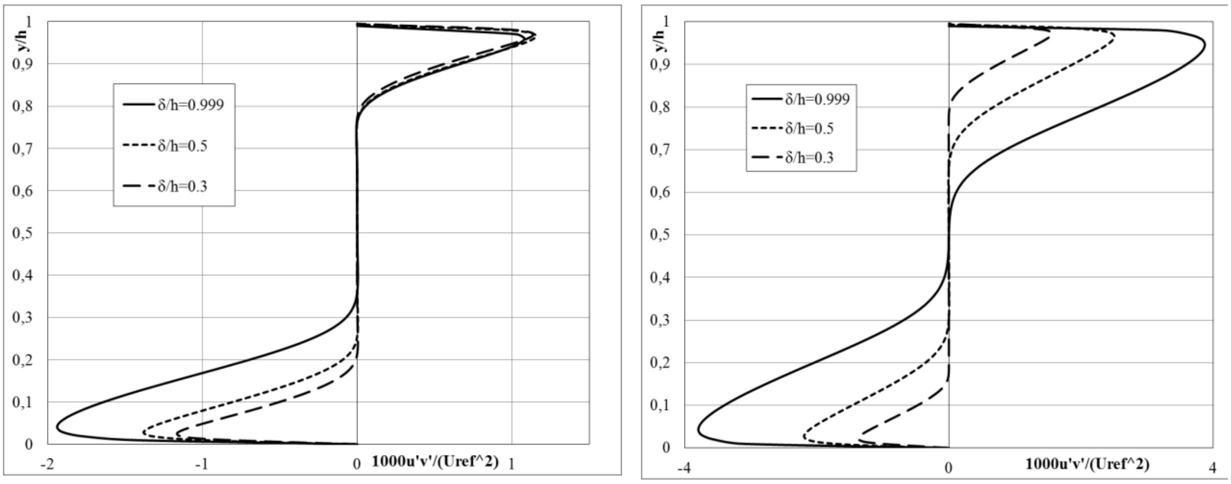
Uref - this is the reference velocity in the central channel used for dimensionless determination of velocity profiles and turbulent shear stress [14].

As can be seen from Fig. 3-a to get a turbulent profile in a long pipe, a longer channel is needed, and in a short Fig. 3-b channel, the velocity profile shows the same result at the inlet and outlet of the channel. It can be seen from the figure that to obtain a turbulent flow profile, you do not need to spend a lot of time calculating for a long channel, but instead you can use the copy condition by Lund et al. [2] as mentioned above.

Fig. 4 shows the results of longitudinal velocity and turbulent shear stress using different schemes and different stretching of the grid. Reynolds number $\mathrm{Re} = 288000$.



a) b)

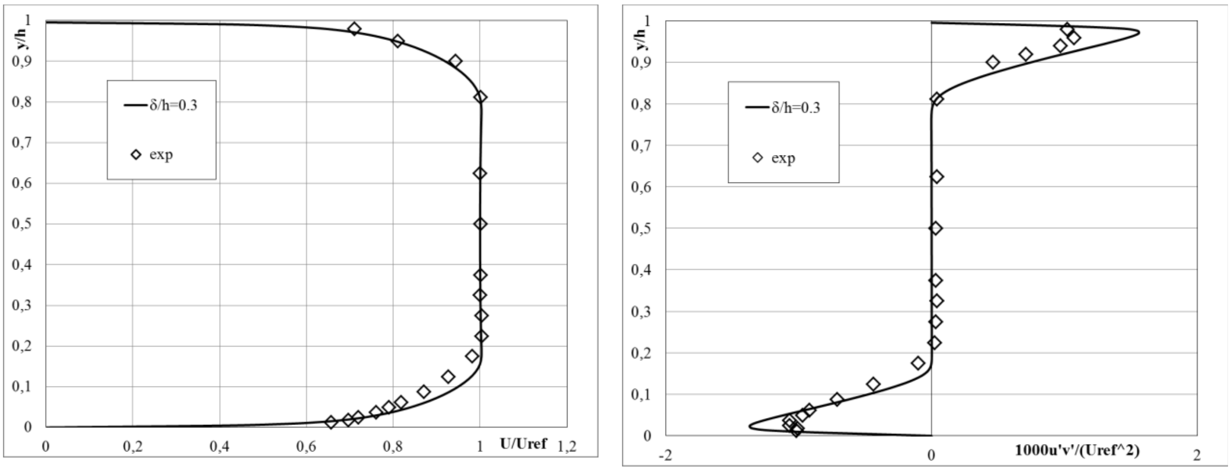


c) d)

Fig. 4. Results of longitudinal velocity (a-b) and turbulent shear stress (c-d) using different schemes, the scheme against the flow (a-c), the McCormack scheme (b-d) in different stretching of the grid.

From Fig. 4. It can be seen when using the scheme against the flow of the longitudinal velocity, two humps appear Fig. 4 (a) and there is no such effect on the McCormack scheme [15].

Now we compare the numerical results of the McCormack scheme with the experimental data of Fig.5. Reynolds number $\mathrm{Re} = 288000$.



a) b)

Fig. 5. Comparison of the numerical results of the McCormack scheme with experimental data

Numerical studies have shown that the McCormack scheme gives more closely results in experimental data.

5. Conclusions

This article shows ways to obtain turbulent flow motion for long and short pipes. Obtaining a profile of turbulent motion in a long pipe requires a long calculation. The profile of turbulent motion is conveniently obtained using the method proposed by Splat and Lund.. When numerically solving the Navier-Stokes equation, the McCormack scheme showed good results with experiment.

REFERENCES

1. Ковеня В. М. Разностные методы решения многомерных задач: Курс лекций // Новосиб. гос. ун-т. Новосибирск, 2004. 146 с.
2. Андерсон Д., Таннехилл Дж., Плетчер Р. Вычислительная гидромеханика и теплообмен: В 2-х т. Т. 1: Пер. с англ. —М.: Мир, 1990. – 384 с.
3. P. R. Spalart and A. Leonard, Direct numerical simulation of equilibrium turbulent boundary layers, in Proc. 5th Symp. on Turbulent Shear Flows, Ithaca, NY, 1985.
4. Lund, T., Wu, X. & Squires, K. (1998). Generation of turbulent inflow data for spatially-developing boundary layer simulations. Journal of Computational Physics, 140, 233–258.
5. Malikov Z. M., Madaliev M. E. Numerical Simulation of Two-Phase Flow in a Centrifugal Separator //Fluid Dynamics. – 2020. – Т. 55. – №. 8. – С. 1012-1028. DOI: 10.1134/S0015462820080066
6. Son E., Murodil M. Numerical Calculation of an Air Centrifugal Separator Based on the SARC Turbulence Model //Journal of Applied and Computational Mechanics. – 2020. https://doi.org/10.22055/JACM.2020.31423.1871
7. Madaliev M. E. Numerical research ν t-92 turbulence model for axisymmetric jet flow //Vestnik Yuzhno-Ural'skogo Gosudarstvennogo Universiteta. Seriya" Vychislitelnaya Matematika i Informatika". – 2020. – Т. 9. – №. 4. – С. 67-78.
8. Madaliev M. E., Navruzov D. P. Research of νt-92 turbulence model for calculating an axisymmetric sound jet //Scientific reports of Bukhara State University. – 2020. – Т. 4. – №. 2. – С. 82-90.
9. Маликов З. М., Мадалиев М. Э. Численное моделирование течения в плоском внезапно расширяющемся канале на основе новой двужидкостной модели турбулентности //Вестник Московского государственного технического университета им. НЭ Баумана. Серия Естественные науки. – 2021. – №. 4. – С. 24-39.
10. Маликов З. М., Мадалиев М. Э. Численное исследование закрученного турбулентного течения в канале с внезапным расширением //Вестник Томского государственного университета. Математика и механика. – 2021. – №. 72. – С. 93-101.
11. Madaliev E. et al. Comparison of turbulence models for two-phase flow in a centrifugal separator //E3S Web of Conferences. – EDP Sciences, 2021. – Т. 264.
12. Маликов З. М., Мадалиев М. Э. Численное исследование воздушного центробежного сепаратора на основе модели турбулентности SARC //Проблемы вычислительной и прикладной математики. – 2019. – №. 6 (24). – С. 72-82.
13. Мадалиев М. Э. У. Численное моделирование течения в центробежном сепараторе на основе моделей SA и SARC //Математическое моделирование и численные методы. – 2019. – №. 2 (22).
14. Malikov Z. M., Madaliev E. U. Mathematical simulation of the speeds of ideally newtonovsky, incompressible, viscous liquid on a curvilinearly smoothed pipe site //Scientific-technical journal. – 2019. – Т. 22. – №. 3. – С. 64-73.
15. Malikov Z. M., Madaliev E. U., Madaliev M. E. Numerical modeling of a turbulent flow in a flow flat plate with a zero gradient of pressure based on a standard k-ε and modernized k-ε models //Scientific-technical journal. – 2019. – Т. 23. – №. 2. – С. 63-67.

16. Abdulkhaev, Zokhidjon Erkinjonovich, Axmadullo Muxammadovich Abdurazaqov, and Abdusalom Mutalipovich Sattorov. "Calculation of the Transition Processes in the Pressurized Water Pipes at the Start of the Pump Unit." *JournalNX* 7, no. 05: 285-291.
17. ABDULKHAEV, ZOKHIDJON ERKINJONOVICH. "Protection of Fergana City from Groundwater." *Euro Afro Studies International Journal* 6 (2021): 70-81.
18. Абдукаримов, Бекзод Абобакирович, Ахрор Адхамжон Угли Акрамов, and Шахноза Бахтиёрбек Кизи Абдухалилова. "Исследование повышения коэффициента полезного действия солнечных воздухонагревателей." *Достижения науки и образования* 2 (43) (2019).
19. Рашидов, Ю. К., Ж. Т. Орзиматов, and М. М. Исмоилов. "Воздушные солнечные коллекторы: перспективы применения в условиях Узбекистана." In *Экологическая, промышленная и энергетическая безопасность-2019*, pp. 1388-1390. 2019.
20. Абдукаримов, Б. А., О. А. Муминов, and Ш. Р. Утбосаров. "Оптимизация рабочих параметров плоского солнечного воздушного обогревателя." In *Приоритетные направления инновационной деятельности в промышленности*, pp. 8-11. 2020.
21. Аббасов, Ёркин. "Роль солнечных воздухонагревателей в теплоэнергетической отрасли и перспективы их развития в Республике Узбекистан." *Общество и инновации* 1, no. 1 (2020): 1-13.
22. Mirsaidov, Mirziyod, Abdurasul Nosirov, and Ismoil Nasirov. "Spatial forced oscillations of axisymmetric inhomogeneous systems." In *E3S Web of Conferences*, vol. 164, p. 02009. EDP Sciences, 2020.
23. Erkinjonovich, Abdulkhaev Zokhidjon, and Madraximov Mamadali Mamadaliyevich. "WATER CONSUMPTION CONTROL CALCULATION IN HYDRAULIC RAM DEVICE." In *E-Conference Globe*, pp. 119-122. 2021.
24. Abdukarimov, B. A., Sh R. O'tbosarov, and M. M. Tursunaliyev. "Increasing Performance Efficiency by Investigating the Surface of the Solar Air Heater Collector." *NM Safarov and A. Alinazarov. Use of environmentally friendly energy sources* (2014).
25. Koraboevich, Usarov Makhamatali, and Mamatisaev Giyosiddin Ilhomidinovich. "CALCULATION OF THE FREE VIBRATIONS OF THE BOXED STRUCTURE OF LARGE-PANEL BUILDINGS." In *" ONLINE-CONFERENCES" PLATFORM*, pp. 170-173. 2021.
26. Мадрахимов, М. М., З. Э. Абдулҳаев, and Н. Э. Ташпулатов. "Фарғона Шаҳар Ер Ости Сизот Сувлари Сатҳини Пасайтириш." *Фарғона Политехника Институти Илмий–Техника Журнали* 23, no. 1 (2019): 54-58.
27. Abdulkhaev, Z. E., M. M. Madraximov, and M. A. O. Shoyev. "Reducing the Level of Groundwater In The City of Fergana." *Int. J. Adv. Res. Sci. Commun. Technol* 2, no. 2 (2021): 67-72.
28. Abdullayev, B. X., S. I. Xudayqulov, and S. M. Sattorov. "SIMULATION OF COLLECTOR WATER DISCHARGES INTO THE WATERCOURSE OF THE FERGHANA VALLEY." *Scientific-technical journal* 24, no. 3 (2020): 36-41.
29. Abdukarimov, Bekzod Abobakirovich, and Yorqin Sodikovich Abbosov. "Optimization of operating parameters of flat solar air heaters." *Вестник науки и образования* 19-2 (2019): 6-9.
30. Abdulkhaev, Zokhidjon, Mamadali Madraximov, Axmadullo Abdurazaqov, and Mardon Shoyev.

"Heat Calculations of Water Cooling Tower." *Uzbekistan Journal of Engineering and Technology* (2021).

31. Xamdamaliyevich, Sattorov Alimardon, and Salimjon Azamdjanovich Rahmankulov. "INVESTIGATION OF HEAT TRANSFER PROCESSES OF SOLAR WATER, AIR CONTACT COLLECTOR." In *E-Conference Globe*, pp. 161-165. 2021.
32. Сатторов, Алимардон Хамдамалиевич, Ахрор Адхамжон Угли Акрамов, and Ахмадулло Мухаммадович Абдуразаков. "Повышение эффективности калорифера, используемого в системе вентиляции." *Достижения науки и образования* 5 (59) (2020): 9-12.
33. Mirsaidov, Mirziyod, Makhamatali Usarov, and Giyosiddin Mamatisaev. "Calculation methods for plate and beam elements of box-type structure of building." In *E3S Web of Conferences*, vol. 264. EDP Sciences, 2021.
34. Abdulkhaev, Zokhidjon Erkinjonovich, Mamadali Mamadaliyevich Madraximov, Salimjon Azamdjanovich Rahmankulov, and Abdusalom Mutalipovich Sattorov. "INCREASING THE EFFICIENCY OF SOLAR COLLECTORS INSTALLED IN THE BUILDING." In *" ONLINE-CONFERENCES" PLATFORM*, pp. 174-177. 2021.
35. Рашидов, Ю. К., М. М. Исмоилов, Ж. Т. Орзиматов, К. Ю. Рашидов, and Ш. Ш. Каршиев. "Повышение эффективности плоских солнечных коллекторов в системах теплоснабжения путём оптимизации их режимных параметров." In *Экологическая, промышленная и энергетическая безопасность-2019*, pp. 1366-1371. 2019.