UDC 621

POLLUTANT DISPERSION ANALYSIS IN WATER FLOW IN GANGA CANAL

Himanshu Joshi[1], Kumar Abhishek[2]
1 - National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine
2 - Department of Water Resource Development & Management Indian Institute of Technology Roorkee, Roorkee-247667, India

Abstract *This paper present the study of pollutant dispersion analysis using CFD model .Canals are the artificial channels for water navigation, to fulfill slack of water for irrigation needs. However, at many places there are several lateral entries of pollutant into the canal and river from household drainage and industrial wastes. It is always desirable to acknowledge the canal water suitability for irrigation and other purposes. The paper is focused to investigate the flow and diffusion of sewage pollutant in the continuous flowing canal water. The investigation has been carried out by developing three-dimensional model of the canal using computational tool ANSYS software.*
Key words: *canal water, pollutant, computational fluid dynamics, mass fraction of pollutant, velocity profile*

1. Introduction Rivers and canals are the major source of good quality water for the living of humans and animals and for the irrigation purposes. Rivers are nurturing all living beings since the time known in history. The oldest civilizations of India, Harappa and Mohenjo-Daro, habituated near Indus River. Many cities of India were nourished by the rivers like Ganga, Yamuna, Krishna, Godawari and Narmada etc. and canals that runs out of these rivers. Irrigation is an artificial way of nourishing crops through quality water. India is an agricultural economy thus most of its cultivated land is dependent on irrigation. The country is dependent on the rivers for this purpose. River Bhagirathi originates from Gangotri thereafter it meets river Alakhnanda at Dev Prayag and after their confluence, the resulting river is often called Ganga. The Alakhnanda river make contributions approximately 66% and the river Bhagirathi make contributions approximately 34% to the river Ganga. The complete structural area of the river Ganges across Haridwar is almost 20,000.00 Km2 in Himalaya Mountains ranges. This river is the life line of gigantic fertile agricultural track of the adjoining districts on it`s both banks. The financial system of the inhabiting farmers typically is dependent upon the irrigation water which is regularly deliver from the river Ganga. In the year 1837 an immediate need of irrigation was felt in the doab due to the loss of almost 8 lakh lives in the region. Colonel Proby Cautley proposed a plan for a canal to counter the problem of drought and irrigation the region. In year 1842 the digging of canal started and in year 1855 the irrigation through the canal was commenced. This canal was named as Ganga Canal which was separated from the main river Ganga at Bhimgoda barrage near Har-ki-Pauri, Haridwar .The canal is administratively classified into the upper Ganges canal and lower Ganga canal which is named similar to upper Doab and lower Doab vicinity respectively. The canal is mainly used for irrigation, although some proportions of it is also used for navigation intent and for its building substances. Originally, the canal had a head discharge of 6000 ft³/s (developed over time from 1842 to 1854). Presently, the Ganga Canal is widened up regularly to regulate the discharge of 295 m³/s. The canal waters virtually 9,000 km² productive agricultural land in the ten districts of Uttarakhand and Uttar Pradesh. In present times, the canal project is the reason of agricultural and environmental prosperity in these two states, and thus irrigation departments of the states keenly preserve the canal system [1].

2. Turbulence model Most of the fluid flows are turbulent which occur in our daily life. Distinctive examples of turbulent fluid flow are, the river, fluid flow in the ocean, canal water flow, flow of fluid in wash basins etc. It is difficult to define turbulent flow in few lines, but it has a number of characteristic features which help in recognizing its regime such as irregularity, diusivity, large Reynolds numbers, 3- Dimensional, Dissipation and Continuum. Modeling of turbulent flow is the development of a model and its use to estimate the turbulence effects. A turbulent fluid flow has characteristic structures of different time and length scales, which all intermingle with each other. To focus on modeling of large-scale and mean flow features of the flow the average the governing equations is obtained for the flow, but for most accurate results the small length scales and fluctuations should also be considered. When the flow is turbulent, the instantaneous flow variables (for example pressure and velocity) should be reduced to average and RMS value. One reason to decompose the variables is that when flow quantities are measured, more emphasis is made upon average values rather than their time responses. Second reason is that Navier-Stokes equation when numerically solved, a refined grid is needed to resolve all turbulent length scales and also need a fine resolution for time scale since turbulent flow is unsteady in nature [2].

There are many model available for turbulence fluid flow among these, K-epsilon (k-ε) model is the very common model used for turbulence in CFD to map average flow characteristics. It comprises of two partial differential equations which provides an account of turbulence. The reason behind development of the model was to replace the Prandtl's mixing-length model, also to look for an alternative to algebraically proposing length scales in moderate to high turbulent flows. The classic k-ε equations comprise of lot of unmeasurable expressions so to bring practical approach in the model, the standard model (Launder and Spalding, 1974 [3]) is opted which is founded on our knowledge of the fluid flow processes, thus reducing unknowns and developing the equations used in most of the fluid flow applications encountering turbulence. Rate of Change of k or ε+ Transport of k or ε by convection = Transport of k or ε by diffusion + Rate of production of k or ε- Rate of destruction of k or ε

For kinetic energy of turbulent flow, k

$$\frac{\partial(pk)}{\partial t}+\frac{\partial(pku_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\epsilon \quad (1)$$

and dissipation of energy ϵ

$$\frac{\partial(p\epsilon)}{\partial t}+\frac{\partial(p\epsilon\epsilon_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\epsilon}\rho\frac{\epsilon^2}{k} \quad (2)$$

Where, ν_i - stands for the velocity component in 'ith' direction, E_{ij} - stands for the component of rate of deformation, μ_t - stands for eddy viscosity.

$$\mu_t=\rho c_\mu\frac{k^2}{\epsilon} \quad (3)$$

The equations also consist of some adjustable constants like $\sigma_k, \sigma_\epsilon, C_{1\epsilon}\ \&\ C_{2\epsilon}$ the constants values can be obtained by repetitive iterations for a wide velocity ranges. These are follows $C_\mu=0.09$, $\sigma_k=1.00$, $\sigma_\epsilon=1.30$, $C_{1\epsilon}=1.44\ \&\ C_{2\epsilon}=1.92$.

3. Species transport model Species transport in homogenous multi component model assumes that all the species are mixed on a molecular level and do not attempt to calculate any slip between the phases. Instead of any mixing this is assumed to come from turbulent diffusion. One set of governing equations plus a species transport equation is solved. This method solves the conservation equations for convection, diffusion, and response sources for more than one aspect species.

$$\frac{\partial}{\partial t}(pY_i)+\nabla\cdot(\rho\vec{v}Y_i)=-\nabla\cdot\vec{J}_I+R_i+S_i \tag{4}$$

This conservation equation describes the diffusion and convection of the mass fraction, of a species where Yi. called production rate by chemical reaction, and Si called rate of creation due to effect of the dispersed phase and input sources. The diffusion flux Ji occurs due to concentration. Fick's law is the default:

$$\vec{J}_I=-\rho D_{i,m}\nabla Y_I-D_{T,i}\frac{\nabla T}{T} \tag{5}$$

Where Di, m stands for mass diffusion coefficient and DT, i is thermal diffusion coefficient. This approximation is conventionally good. With turbulence, accommodation is necessary as mixing must be explicitly included as function of turbulence at shorter length scales.

4. Analysis based on species transport model. Mass transport study is done in fluid mechanics to obtain velocity field of flowing fluid in any control volume. Most of the transport phenomenon is probabilistic or statistical in nature because of erratic continuous motion of fluid particles. The governing laws which govern the transport phenomena are generally, continuity and Navier stokes equations, describe how the quantity being studied must be conserved. The continuity equation confirms the conservation of mass making the fluid flow valid and Navier-Stokes equations describes the relationship between fluid flux and the forces applied to the fluid. Mass Transfer in a system is governed by Fick's First Law. Diffusion flux is dependent on concentration gradient and the diffusivity of the substance in the flow going on from higher concentration to lower concentration. In the present study the sewage pollutant particles are getting mixed and transported along the stream flow of the canal.

4.1. Effect of sewage velocity. The dispersion of sewage pollutant at constant sewage velocity but the effect of sewage velocity on different parameters has also been analysed in fig. 1. It was observed that dispersion of sewage pollutant in to the upper Ganga canal increases with the increase of velocity of sewage flow. This observation that has been tracked at outlet of canal (at Ganeshpur Bridge) from fig. 1. that most of the dispersion effect of sewage pollutant has been observed near the left wall and further increases with the velocity of sewage along the width but rate of mass fraction of sewage pollutant reduces and fraction of sewage pollutant is more concentred in left side at outlet near the wall of canal as shown in fig.1. Whereas, mass fraction of sewage is found very less in right side of canal due to less diffusion of pollutant.

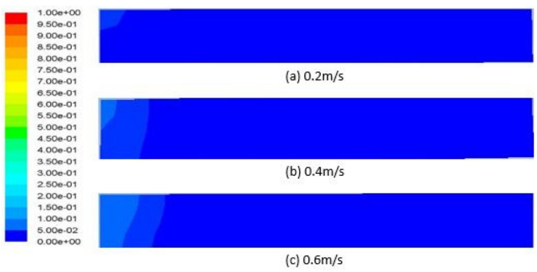

Fig. 1. - Contour of mass fraction of sewage pollutant at outlet of canal with five Open Sewage inlet.

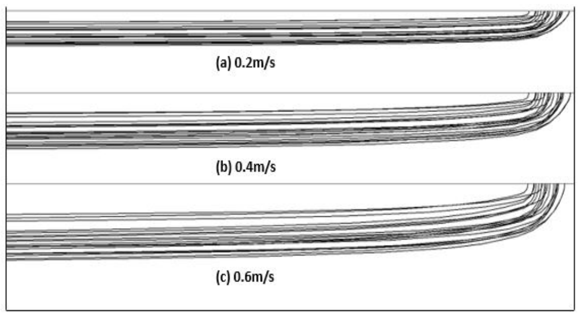

Fig. 2. - Flow behavior of sewage pollutant in canal

To predict the flow behaviour of sewage pollutant from individual sewage inlet, path line has been developed as shown in fig. 2. these path line indicates that effect of sewage pollutant from the top surface are increasing along the direction of fluid flow with the increase of velocity of sewage pollutant.

To analyse the result quantitatively, the mass fraction of the sewage pollutant has been tracked at the outlet of the computational domain (near to Ganeshpur Bridge). The fig. 3. shows the variation of mass fraction of sewage pollutant obtained at the outlet of canal after applying species transport model in the analysis of upper Ganga canal near Ganeshpur Bridge. This graph depicts that with the increase in velocity mass fraction of pollutant is also increasing at the outlet of the canal. It is due to less time available for diffusion of pollutant within the canal water with respect to velocity of the flow. As the length of canal outlet is constant and sewage velocity is increased, this modelled cause shows that with the increase in velocity, diffusion within the pollutant is poor which cause an abrupt increase in fraction of the pollutant at the Ganeshpur Bridge. Steepness in the flow of sewage with mentioned velocity in the fig. 3. depicts an in-depth perspective of time with which the pollutant of respective sewage opening reaches the outlet. As it can be seen clearly from the graph that sewage opening which is more near to the outlet reaches outlet within less time when compared with the farthest sewage. Abrupt mixing of pollutant with opened sewages at an increased rate with increase in velocity. Equilibrium position of the sewage pollutant amount is achieved at the same time irrespective of the velocity, as it can be clearly seen from the fig. 3.

5. Objective The objective of present work is to model the upper Ganga canal Roorkee and numerically simulate to predict the pollutant dispersion in two phase fluid flow CFD model of Roorkee Upper Ganga Canal (UGC) and validation based on velocity at different divergence will be performed to check the accuracy and trust worthiness of the model. Present study aims with the following specific objectives:

- To study the change in concentration of water by addition of pollutant from different sewage position.
- To study the effect of change of inlet velocity of sewage.

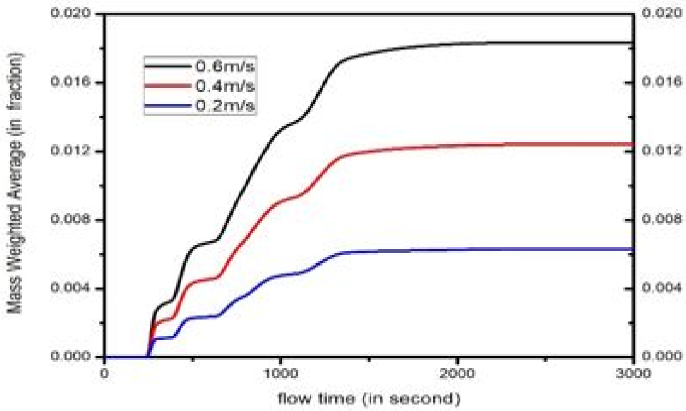

Fig. 3. - Variation of Mass weighted average of sewage pollutant with flow time at different velocity of sewage

6. Conclusion

- It was observed that at higher velocities, the rate of mass fraction of tracer at outlet decreased and dispersion increased. Concentration of pollutant toward the depth along the canal also decreased because of diffusion process in case of species transport analysis.
- Although concentration of pollutant was decreasing from the main source of pollutant with the time along the canal for a fixed velocity of sewage as a result of dispersion.
- Dispersion of pollutant was observed to be increasing along the width of specified domain with respect to opening of sewage.
- Effect of pollutant dispersion toward the depth was increasing along the longitudinal

References:

1. *Upper Ganges Canal. The imperial* Gazette of India V. 12 p. 138. Brown, Joyce (1980), A Memoir of Sir Proby Cautley. Colonel Sir Proby T Cautley. Report on the Ganges Canal Works, from the commencement until the opening of the Canal in 1854 (London Smith Elder and Co. 1860).
2. *Ganges Canal,* Compiled by Sir Proby Thomas Cautley, Publisher C.E.C. Press 1854. The Ganges Canal by Arthur Cotton. Jan Lucassen, The brickmakers' strikes on the Ganges canal in 1848-1849
3. *Division, W. R. (1995) 'Simulation* models for conservative and neoconservative solute Transportation ROBERT L. RUNKEL', Water, (226), pp. 153–159.