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TWO PHASE POLLUTANT DISPERSION ANALYSIS IN WATER FLOW IN CANAL

Abstract

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 from household drainage and industrial wastes. It is always desirable to acknowledge the canal water suitability for irrigation and other purposes. The present dissertation work 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: Computational Fluid Dynamics (CFD); ANSYS Fluent; k-ε turbulence model; canal water; Species transport model; Mixture model

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[1].

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 as shown in fig. 1.1. Initially the Ganga Canal irrigates Doab vicinity between the Ganga and the Yamuna River[2] .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 ft^3/s (developed over time from 1842 to 1854). Presently, the Ganga Canal is widened up regularly to regulate the discharge of 295 m^3/s. The canal waters virtually 9,000 km^2 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.

Literature Summary

This section comprises mainly of exploration of effects and inter-relation of critical pollutant parameters affecting the river quality. As, studies have been done for determination of physico-chemical characteristics of a river for determining parameters affecting the water quality, also accountability of urban waste in river water quality was explored, majorly evaluating the effect of critical pollutant on river water quality through sectional sampling analysis. Also, effect of phytoplankton groups and it's relation with the NO2, NO3-, SiO3, HCO3, PO4, Ca, Mg on a river at different site were studied.

Fig.1.1 starting point of Upper Ganga Canal[4]

Also, it is seen that much work has been accomplished in the development of mathematical model for studying fluid flow pattern and mixing of sewage pollutant in canal and River. To improve the water quality in river and canal water flow, turbulence diffusion model, mixture model, OTIS, OTIQ and matrix transmission method were used. The result shows that these model significantly affect the fluid flow in canal water and river. The effect of entry of pollutant on fluid flow and multiphase flow were also discussed with such model by researcher.

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, diffusivity, 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.

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

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\epsilon \tag{3}$$

and dissipation of energy ϵ

$$\frac{\partial(\rho\epsilon)}{\partial t}+\frac{\partial(\rho\epsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\epsilon}\frac{\partial\epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}2\mu_{tE_{ij}E_{ij}}-C_{2\epsilon}\rho\frac{\epsilon^2}{k} \tag{4}$$

Where,

v_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

$$\mu_{t=\rho C_\mu}\frac{k^2}{\epsilon} \tag{5}$$

The equations also consist of some adjustable constants like σ_k, σ_ϵ, $C_{1\epsilon}$ & $C_{2\epsilon}$ the constants values can be obtained by repetitive iterations for a wide velocity ranges. These are follows

$C_\mu = 0.09$, $\sigma_k = 1.00$, $\sigma_\epsilon = 1.30$, $C_{1\epsilon} = 1.44$ & $C_{2\epsilon} = 1.92$

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..

$$\frac{\partial}{\partial t}(\rho Y_i)+\nabla.(\rho\vec{v}Y_i)=-\nabla.\vec{J_i}+R_i+S_i \tag{6}$$

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:

$$\vec{J_i}=-\rho D_{i,m}\nabla Y_i-D_{T,i}\frac{\nabla T}{T} \tag{7}$$

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.

Mixture model

The mixture model is defined with two of multiphase (fluid or particulate). The mixture model is a simple model for multiphase flows where phases move at unlike velocities. Homogenous multiphase flows can also be modeled using this model in which phases have very strong coupling. Using thee Eulerian model, the phases can be treated as intermingling continua. The model solves the continuity equation for the mixture, the mixture momentum equation, the energy equation for the mixture, and equation of volume fraction for the subsidiary phases and suggests relative velocities of the dispersed phase. The mixture model proved as a good alternate of the Eulerian model for multiphase in numerous applications. A complete multiphase model may not be applicable when particulate phases are widely spread or when governing laws of interphase not known. Application of the mixture model consist of particle-laden which flows with less loading, sedimentation, flows having bubbles, and cyclone separators. The model can be applied without relative motion of the dispersed phase to model homogenous multiphase flow. The continuity equation for the mixture is

$$\frac{\partial(\rho_m)}{\partial t} + \nabla.(\rho_m \overrightarrow{v_m}) = \dot{m} \tag{8}$$

Where, v_m is mass-averaged velocity

$$\overrightarrow{v_m} = \frac{\sum_{k=1}^{n} \alpha_k \rho_k \overrightarrow{v_k}}{\rho_m} \tag{9}$$

And, ρ_m is mixture density:

$$\rho_m = \sum_{k=1}^{n} \alpha_k \ \rho_k \tag{10}$$

α_k Stands for volume fraction of phase k and m is mass transfer because of cavitation or user-defined sources of mass. The equation of momentum balance for mixture can be obtained by adding individual momentum balance equation of all phases expressed as

$$\frac{\partial}{\partial t}(\rho_m \vec{v}_m) + \nabla \cdot (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \nabla.\left[\mu_m\left(\nabla\overrightarrow{v_m} + \nabla\overrightarrow{v_m^T}\right)\right] + \rho_m \vec{g} + \vec{F} + \nabla.\left(\sum_{k=1}^{n} \alpha_k \rho_k \ \vec{v}_{dr,k} \ \vec{v}_{dr,k}\right) \tag{11}$$

where n is the number of phases, and F is a body force, μ_m is the viscosity of the mixture

$$\mu_m = \sum_{k=1}^{n} \alpha_k \mu_k \tag{12}$$

Volume Fraction Equation for the Secondary Phases

In the continuity equation for subsidiary phase p, the equation of volume fraction is calculated as:

$$\frac{\partial}{\partial t}(\alpha_p \rho_p) + \nabla.(\alpha_p \rho_p \vec{v}_m) = -\nabla.(\alpha_p \rho_p \vec{v}_{dr,p}) \tag{13}$$

Where $\alpha_k$the volume fraction of secondary is phase p and $v_{dr,p}$ is the drift velocity of phase.

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.

Conclusion

The capability of CFD, in this study, was explored to model complex two phase fluid flow in canal. The commercial CFD software (FLUENT) was found capable to successfully model the pollutant dispersion in water flow. Following conclusions have been drawn on the basis of present study.

- 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.
- In this study, dispersion effect of pollutant in water flow was maximum up to 20m from the side wall of domain along the width, this maximum effect had been observed at outlet.
- Effect of pollutant dispersion toward the depth was increasing along the longitudinal direction with subsequently opening of sewage.

Future scope

The present research work aimed at developing the methodology for calculating the direction of flow, amount of dispersion and mixing time with which the unwanted or wanted pollutant would disperse in the flowing water. This study work can be used by the researchers to developed the methodology for issuing warning to public and concerned authorities for various pollutant (industrial effluent, pollutant of sewage treatment plant, automobile pollutant etc.) dispersion in the running river, researchers can conduct their research on chemicals like sulphate ions, nitrate ions, calcium ions, BOD, COD dispersion into the river through CFD analysis using mixing model and specific transport model. The analysts may additionally specify a couple of chemical reactions to model simultaneously, with reactions taking place either in the bulk go with the flow, at wall or particle surfaces, or in the porous place.

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