CFD MODELING OF SLURRY FLOWS THROUGH HORIZONTAL PIPELINES

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by

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CERTIFICATE

This is to certify that the thesis "**CFD MODELING OF SLURRY FLOWS THROUGH HORIZONTAL PIPELINES**" being submitted by **MR. MANOJ KUMAR GOPALIYA** to the Indian Institute of Technology Delhi, New Delhi (India) for the award of the degree of **Doctor of Philosophy** in Civil Engineering Department is a bonafide research work carried out by him under my supervision and guidance. The thesis in my opinion, has reached the standard fulfilling the requirements for the Doctor of Philosophy Degree. The research report and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma**.**

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ABSTRACT

Solid-liquid flows are widely employed in industry and nature. Many liquid-solid mixtures used across a wide spectrum of industries such as mineral, chemical and power industries are found to be transported by pumping through pipelines. Determining the most efficient and economical process of pumping these solids in carrier liquid requires careful consideration and analysis of different factors, some of which can have a significant impact on performance and cost of whole process including environmental regulations of the land. It supports the greater need for more fundamental understanding of different aspects of the behaviour of materials in such slurry pipeline systems.

The high economical and technical cost of experimental testing of slurry pipelines and the limitations of the existing simplified empirical/semi-empirical models in general has helped in making computational fluid dynamics (*CFD*) an attractive alternative in recent years especially in the field of slurry pipeline research. This along with ever decreasing cost to computing supports the need of better understanding of *CFD* techniques and its applications in the field of slurry flow analysis.

The present Ph. D. research work has bridged this gap by undertaking a much exhaustive *CFD* analysis of slurry flows through horizontal pipelines. During the present research work, experimental results of different researchers spread over much wider range of working parameters viz. pipe diameter, grain size, slurry flow velocity, efflux concentration, solid density etc. have been selected and simulated.

Since all selected slurry flow cases have already been tested experimentally by various researchers, the outcome of present study have enriched the existing experimental results with exhaustive and additional information of different slurry flow parameters which otherwise are quite expensive and many times impossible to obtain through experiments. The

exhaustive information of different slurry flow parameters obtained using *CFD* simulations have been analyzed and presented in the form of graphs showing the effect of variations in different geometric and working input slurry flow parameters on the results of important design parameters of slurry flow transportation system. Specifically, effect of slurry flow velocity and efflux concentration on important design parameters such as solid concentration distribution, solid velocity distribution, pressure drop, friction factor, granular pressure, turbulent viscosity and flow turbulence have been presented for slurry flows through different sized horizontal pipelines. Both qualitative and quantitative analyses have been presented. This helps in evaluating the performance of existing systems leading to future up-gradation in it for improved output.

The present research work has also undertaken a selective analysis of effect of grain size on important design parameters of slurry flow transportation system. A series of slurry flow cases having different grain sizes and input working parameters flowing through three different pipe sizes have been simulated. Simulation results have been presented showing effect of grain size on solid concentration distribution, solid velocity distribution, pressure drop, friction factor, granular pressure, turbulent viscosity and flow turbulence.

The present research work also includes parametric analysis of important simulation parameters for slurry flows through horizontal pipeline. In this, effect of different turbulence models, wall function and wall boundary conditions on important design parameters of slurry flow transportation systems have been analyzed and presented.

During this research, correlations for important design parameters viz. solid concentration distribution, solid velocity distribution, pressure drop, turbulent kinetic energy and its dissipation rate have also been obtained in terms of different geometric and working input slurry flow parameters using non-linear regression of exhaustive data obtained during *CFD* simulations. Genetic algorithm (*GA*) has also been applied on these data set for better understanding of results. The equations mentioned here correspond to the simulation data of important slurry flow parameters presented in the form of best fit surface curves. These equations do not pertain to all the data points. Rather, they represent only the best fitted surfaces as per regression algorithms. Therefore, these equations should not be expected to predict all the values of flow parameters in the prescribed range.

The outcomes of the present research work presented in both qualitative and quantitative manner for different slurry flow parameters for solid-liquid slurry flows through horizontal pipelines have further enriched this research field quite extensively.

सार

तरल-ठोस प्रवाह उद्योग और प्रकृति में व्यापक रूप से नियोजित होते हैं। खनिज, रासायनिक और बिजली उद्योग जैसे उद्योगों के विस्तृत स्पेक्ट्रम में उपयोग किए जाने वाले कई तरल-ठोस मिश्रण पाइपलाइनों के माध्यम से पंप करके पहुँचायें जाते हैं। वाहक तरल में इन ठोसों को पंप करने की सबसे कुशल और किफायती प्रक्रिया को निर्धारित करने के लिए विभिन्न कारकों के सावधानीपूर्वक विचार और विश्लेषण की आवश्यकता होती है, जिनमें से कुछ भूमि के पर्यावरणीय नियमों सहित संपूर्ण प्रक्रिया के प्रदर्शन और लागत पर महत्वपूर्ण प्रभाव डाल सकते हैं। यह ऐसी घोल पाइपलाइन प्रणालियों में सामग्रियों के व्यवहार के विभिन्न पहलुओं की अधिक मौलिक समझ के लिए आवश्यकता का समर्थन करता है।

घोल पाइपलाइनों के प्रयोगात्मक परीक्षण की उच्च आर्थिक और तकनीकी लागत और सामान्य सरलीकृत अनुभवजन्य / अर्ध-अनुभवजन्य मॉडल की सीमाओं ने सामान्य रूप से संगणनात्मक तरल गतिशीलता (सीएफडी) को हाल के वर्षों में एक आकर्षक विकल्प बनाने में मदद की है, खासकर घोल पाइपलाइन अनुसंधान के क्षेत्र में । संगणना की लगातार कम होती लागत, घर्षण प्रवाह विश्लेषण के क्षेत्र में सीएफडी तकनीकों और उसके अनुप्रयोगों की बेहतर समझ की आवश्यकता का समर्थन करता है।

वर्तमान पीएचडी अनुसंधान कार्य ने क्षैतिज पाइपलाइनों के माध्यम से घोल प्रवाह के बहुत व्यापक सीएफडी विश्लेषण के द्वारा इस अंतर को कम करने का प्रयास किया है। वर्तमान शोध कार्य के दौरान,

विभिन्न शोधकर्ताओं के प्रयोगात्मक परिणाम जो की कामकाजी मानकों की विस्तृत श्रृंखला में फैले हुए हैं आदि का चयन और अनुकरण किया गया है।

चूंकि सभी चयनित घोल प्रवाह मामलों का प्रयोग पहले से ही विभिन्न शोधकर्ताओं द्वारा प्रयोगात्मक रूप से किया जा चुका है, वर्तमान अध्ययन के नतीजे मौजूदा प्रयोगात्मक परिणामों को समृद्ध और विभिन्न घर्षण प्रवाह मानकों की अतिरिक्त जानकारी के साथ समृद्ध कर रहा है जो अन्यथा काफी महंगा हैं और कई बार प्रयोगों के माध्यम से प्राप्त करना असंभव है। सीएफडी अनुकरण का उपयोग करके प्राप्त विभिन्न घोल प्रवाह मानकों की विस्तृत जानकारी का विश्लेषण किया गया है। साथ ही, घोल प्रवाह यातायात प्रणाली के महत्वपूर्ण प्रारुप मानकों के परिणामों पर विभिन्न ज्यामितीय और काम करने वाले घोल प्रवाह निवेश मानकों में विविधता के प्रभाव को रेखाचित्र के रूप में प्रस्तुत किया गया है। इसमें गुणात्मक और मात्रात्मक विश्लेषण दोनों प्रस्तुत किए गए हैं। यह मौजूदा व्यवस्था के प्रदर्शन का मूल्यांकन करने में मदद करता है जिससे उन्नत उत्पादन के लिए भविष्य में उन्नयन होता है।

वर्तमान अनुसंधान कार्य ने घोल प्रवाह परिवहन प्रणाली के महत्वपूर्ण प्रारुप मानकों पर दाने के आकार के प्रभाव का एक चुनिंदा विश्लेषण भी किया है। तीन अलग-अलग पाइप आकारों के माध्यम से बहने वाले विभिन्न आकार के दाने और काम करने वाले निवेश मानकों वाले घोल प्रवाहो की एक श्रृंखला का अनुकरण किया गया है। अनुकरण के परिणाम ठोस एकाग्रता वितरण, ठोस वेग

वितरण, दबाव गिराव, घर्षण कारक, दानेदार दबाव, अशांत चिपचिपाहट और प्रवाह अशांति पर दाने के आकार का प्रभाव दिखाते हुए प्रस्तुत किए गए हैं।

वर्तमान शोध कार्य में क्षैतिज पाइपलाइन के माध्यम से घोल प्रवाह के लिए महत्वपूर्ण अनुकरण मानकों का अनुकरणीय विश्लेषण भी शामिल है। इसमें, घोल प्रवाह परिवहन प्रणालियों के महत्वपूर्ण प्रारुप मानकों पर विभिन्न अशांति मॉडल, दीवार फलन और दीवार सीमा की स्थितियों का प्रभाव प्रस्तुत किया गया है।

इस शोध के दौरान, महत्वपूर्ण प्रारुप मानकों जैसे ठोस एकाग्रता वितरण, ठोस वेग वितरण, दबाव गिराव, अशांत गतिशील ऊर्जा और इसकी अपव्यय दर के लिए सहसंबंध प्रस्तुत किये गए है। इन्हे सीएफडी अनुकरण के दौरान प्राप्त संपूर्ण आकड़ो के गैर-रैखिक प्रतिगमन का उपयोग करके विभिन्न ज्यामितीय और काम कर रहे घोल प्रवाह निवेश मानकों के रूप में प्रस्तुत किया है। परिणामों की बेहतर समझ के लिए इन आकड़ो पर जेनेटिक एल्गोरिदम (जीए) भी लागू किया गया है। यहां वर्णित समीकरण सर्वोत्तम फिट सतह के रूप में प्रस्तुत महत्वपूर्ण घोल प्रवाह मानकों के अनुकरण आकड़ो से मेल खाते हैं। ये समीकरण सभी आकड़े बिंदुओं से संबंधित नहीं हैं। इसके बजाय, वे प्रतिगमन एल्गोरिदम के अनुसार केवल सर्वोत्तम फिट सतहों का प्रतिनिधित्व करते हैं। इसलिए, इन समीकरणों से निर्धारित सीमा में प्रवाह पैरामीटर के सभी मूल्यों की भविष्यवाणी करने की उम्मीद नहीं की जानी चाहिए।

वर्तमान शोध कार्य में क्षैतिज पाइपलाइनों के माध्यम से ठोस तरल घोल प्रवाह के लिए अलग-अलग घोल प्रवाह पैरामीटर के लिए गुणात्मक और मात्रात्मक दोनों तरीके से प्रस्तुत परिणामों ने इस शोध क्षेत्र को काफी व्यापक रूप से समृद्ध किया है।

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