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論文内容の要旨

This thesis consists of five chapters. Chapter 1 is a summary containing the background and purpose of the thesis. Transport of slurries in pipelines has been considered economically and environmentally to be beneficial compared to the conventional modes by road and rail. High concentration slurry systems are especially designed to reduce water usage for long pipelines. The systems, which are usually applied to conveyance of coal and tailings disposal, can also decrease not only contamination of underground and surface water, but also dust emissions and energy consumption.

Important parameters for designing the slurry pipeline systems are pressure drop, critical deposit velocity, concentration, pipe diameter, and so on. Pipeline designers need to accurately evaluate these system characteristics to construct an efficient and cost effective operation.

The mining processes of crushing and grinding ores produce non-uniform sized particles for transport. Due to the complex behaviour of solids in multi sized slurries, reasonable correlations for designing the systems have not yet been reported. Most of the proposed correlations of pressure drop are inclined to apply to uniform sized slurries.

In this study theoretical models were developed for prediction of hydraulic gradient of mixed-sized slurries, through the validity with experimental data. Conventional correlations proposed by Wasp et al. and Condolios-Chapus were also discussed.

In chapter 2, the database of slurry flow was discussed. It is common for researchers to use experimental data to confirm the applicability of the correlations. Since most correlations are empirical, the application would be limited to the range of transport conditions of the slurry flow experiments. Based on theoretical considerations, the correlations of hydraulic gradient of slurry flows were derived in this study. The application ranges should be verified with variety of experimental data covering practical conditions.

Although numerous experiments have been conducted in the past years, few have been published in reports, while some lack detailed information of the transport parameters. To provide accessible and reliable data, a slurry transport database was developed not only for accumulating data, but also for editing, sorting, storing it, and display results in graph plots. By using the database, experimental data was collected from different researchers with varying conditions of transport. Unit conversion was required to unify the data arrangement, and then input and saved on Microsoft Excel with the .csv format. The range of accumulated data was from the 1-in diameter pipeline in this study, to the larger-scale pipeline system of Gillies (1933) of approximately 20-in diameter.
Data characterisation was performed through the use of star graphs with six axes, which clearly distinguished the different transport conditions used by each researcher.

In chapter 3, a single sized model for predicting hydraulic gradient of settling slurry flows was developed. The concentration profiles of solids were applied to evaluate the flow pattern of slurries. Concentration distribution curves produced characteristic planes, with a geometric centre of gravity G, and an angle of Vertex θ. The value of the angle θ represents a solids movement between pseudo-homogeneous and saltation flows.

Thereafter, depending on the flow regime, hydraulic gradient could be estimated with equations that were derived through the consideration of energy consumed for the flow of slurry. By using the database, the analytical model was confirmed to be valid for prediction of hydraulic gradients of settling slurries, although a generalised particles Reynolds number should be applied to give more accurate results.

The parameter of Specific Energy Consumption was introduced to determine the optimum conditions of transport, depending on the pipe diameter and solids concentration.

In chapter 4, innovated models for mixed-sized slurry flows were discussed following

the success with the verification of the settling slurry model. On account of the intricate interactions of solids in multi sized slurries, the solids in the slurries could be split into two portions by the critical particle size. In this study, two models which are based on solids distribution were developed: course-coarse model for slurries with two different sizes of coarse solids, and coarse-fine model for slurries containing two different solids of coarse particles and high concentration-fines. Fine solids were defined as particles of diameter less than 0.25 mm, according to the classification proposed by the United States Department of Agriculture - soil textural classification guide.

Most researchers have recommended the use of the Wasp method for predicting hydraulic gradient of heterogeneous-homogeneous mixed slurries. While the calculation results from the Wasp method showed somewhat good agreement with experimental data, the accuracy was limited to slurries in the regions of lower concentrations. On the other hand, the innovated models showed better correlation with experimentals, although scattering was observed in unstable flow regions. Data from the prototype hydraulic transport of soil residue from coal mining, confirmed that the models can be reasonably applied to commercial pipeline operations. The innovated slurry models proved to satisfy the accuracy of relative error ±20%.

The final chapter briefly concludes analytical results in this study.

論文審査結果の要旨

地上または地中に敷設したパイプラインにて石炭，鉱石，土砂等と水とのスラリー（固体混合液）を搬送するスラリー輸送の設計に当たっては，その輸送システムの正確な水力勾配（圧力損失）と最適な輸送速度を算定する必要がある。しかるに，資源開発において輸送の対象となる固体粒子は，一般に広い粒度分を有し，このことがスラリーの管路内流動現象を複雑にし，これまで多くの研究者によって提案されてきた水力勾配や実用速度の式が，必ずしも十分な計算精度を保証するとは限らず，とくに，大口径管のスラリー輸送の水力勾配を算定することは難しいとされてきた。

本研究では，均一な粒度の固体粒子を含む沈降性スラリーならびに微・粗粒子混合スラリーの流動メカニズムについて理論的に考察し，解析モデルに基づく計算結果が広範囲の実測データを十分な精度で満足することを確認した。

本論文は全文 5 章から構成され，その概要は以下のとおりである。

第 1 章は緒論であり，本研究の背景，従来の研究の状況と問題点ならびに本研究の主たる目的を述べ，これに続く各章の関連性を説明した。

第 2 章では，計算式または解析モデルの検証に不可欠なスラリー輸送データベースの構

築とその応用について考察した。データのコンピュータ入力，修正，整理，蓄積の機能ならびにグラフ機能を有するデータ処理プログラムを開発し，これまで公表された約 3,000 に及ぶスラリー輸送実験データについてスターグラフ分析を行った結果，研究者各自の実験条件およびデータ特性は図式表示されること，また，このデータベースは，水力勾配の計算式の検証に有効であることが確認された。

第 3 章では，固体粒子の径が均一な沈降性スラリーの解析モデルについて理論的に検討した。 Turbulent Schmidt 数等により修正された拡散方程式の数値解が管内の濃度分布を表わすとき，その濃度分布曲線と座標軸から形成される濃度特性平面の重心の値を用いると，スラリーの流動状態が数値化し得ること，さらにスラリーの流動に必要なエネルギーを実用上，十分な精度で算定できることを明らかにした。

第 4 章では，混合粒子径スラリーの解析モデルとして，固体粒子の粒度分布に応じた 2 種のモデルすなわち微・粗粒子混合スラリーモデルおよび異径粗粒子混合スラリーモデルを提案し，いずれの解析モデルも，低流速域の不安定なスラリーの流動域を除くと，従来発表されている計算方法に比べて，高い精度の水力勾配値を与えることが確認された。なお, 管径 203mm のプロトタイプ輸送システムのデータにより解析モデルの検証を行った結果，本研究で提示した水力勾配の計算方法では，特別なスケールアップ法を要しないことが明らかになった。

第 5 章は総括であり，本論文で得られた結果を各章ごとにまとめるとともに，スラリー輸送設計上の注意点について述べた。

以上，要するに，本論文は，沈降性スラリーの流動ならびにその輸送設計について理論的・実験的に検討したものであり，資源学の発展に寄与するところが大である。

よって，本論文は博士論文として十分価値があり，「合格」に価すると認められる。