● *Powder & Multiphase Flow Simulator*

iGRAF

iGRAF makes impossible, possible.

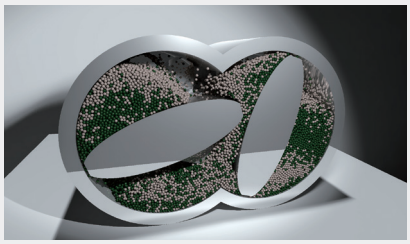
構造計画研究所
KOZO KEIKAKU ENGINEERING Inc.

Product Overview

iGRAF (Integrated Granular Flow Simulation Software) is an integrated simulation software that enables both powder and fluid simulation (CFD) based on the Discrete Element Method (DEM). While emphasizing on ease of use, iGRAF achieves both user-friendliness and reliability on calculation results through implementation of various physical models published in renowned international journals.

What's Powder Simulation

Powder simulation is a technique to reproduce the real phenomena in a computer by calculating the movement of powders and fluids. Numerical results obtained through simulation can be used for further analysis to understand the cause of any challenge.



Benefits of iGRAF

Limit experimental approach

Physics of powders is extremely complex, and in fields involving powder processes, it is common to carry out actual machinery testing to make decisions about commercialization and manufacturing processes. Judgments based on experimental approaches are susceptible to human-dependent factors and are prone to loss of quantitative and objective measures.

Digitalization of powder processes

iGRAF can reproduce powder processes in digital space through simulation. This means that not only can quantitative assessments be made, but also challenging ideas and improvement proposals can be evaluated and examined with minimal risk.

Conversion of development / improvement process

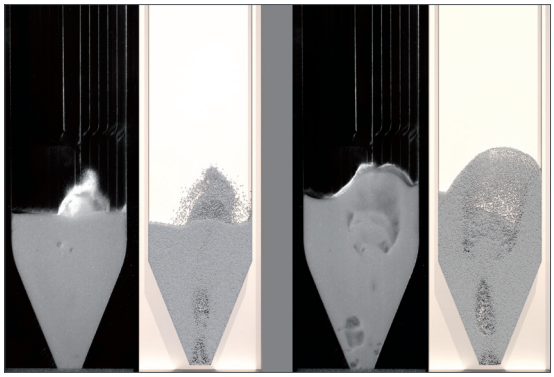
Simulation allows various studies to be carried out safely and quickly without the need for actual equipment. This can lead to reduced prototyping cost, raw material wastage and energy consumption, and can also contribute to the SDGs.

SDGs : Sustainable Development Goals)

iGRAF 3

1 Simulation of Real-scale system

iGRAF enables real machine scale simulation by reducing the computational load with its uniquely developed coarse-grained model and by speeding up and stabilizing calculations through parallel computations and implicit algorithms.

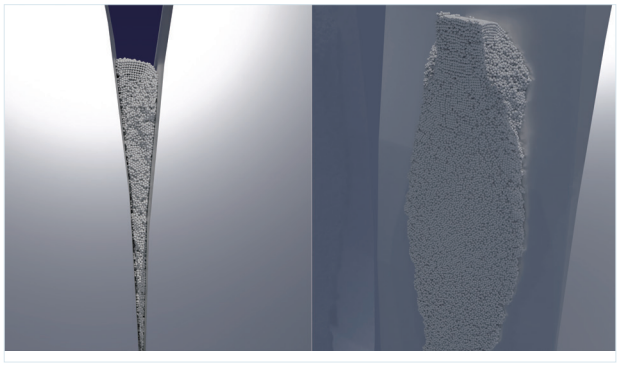


An example of verification with fluidised bed
Background : Black(Experiment),White(Simulation)

Main Features

2 Excellent Reproducibility with High Performance Physical Models

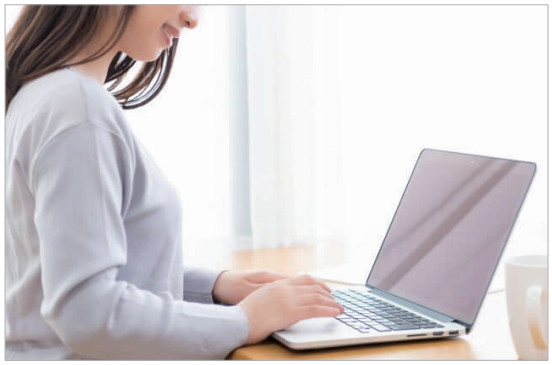
Main feature of iGRAF is its built-in CFD (fluid) solver. Powder phenomena with significant fluid effects can be simulated with iGRAF alone, without relying on empirical models. It is also equipped with high-performance physical models such as unique liquid bridge force model that exhibit excellent reproducibility for a wide range of processes.



Example considering Liquid bridge force

3 User-friendly GUI

To emphasis on ease of use for beginners in simulation, designs such as random arrangement of particles (Feature for particle arrangement) for easier replication of realistic initial condition, mesh-independent geometry recognition technology, function to support setting, in-built mixing index evaluation tool, coupled calculation, etc. are developed.



Easy-to-use GUI

Technical support by Prof. Mikio Sakai University of Tokyo

Prof. Mikio Sakai from University of Tokyo, an authority in the field of powder simulation, was invited by KKE Inc. to be the Special Technical Advisor to develop iGRAF while incorporating the latest analytical technologies. For users who wish to use iGRAF, we offer a robust technical support with Prof. Mikio Sakai, which includes consultation on advanced analysis themes.

Professor Mikio Sakai
Nuclear Engineering & Management
School of Engineering, The University of Tokyo
Visiting Reader, Imperial College London,
Visiting Professor, The University of Surrey
Special Technical Advisor, KKE

Prof. Mikio Sakai specialized in numerical simulation of powder and multiphase flows. In Japan, he is the Director of Society of Powder Technology, Coordinator of the Association of Powder Process Industry and Engineering (APPIE), Chairman of the AI Technology Utilization Committee and in overseas, he is a Visiting Professor of Imperial College London in UK and Visiting Professor at University of Surrey in UK. He is one of the internationally active researcher in the field of powder and multiphase flow simulation and also been selected as an editorial member of world renowned journals such as Chemical Engineering Science and Granular Matter.

Analysis Cases

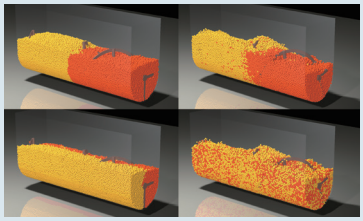
Using iGRAF, numerous insights and suggestions can be obtained from simulation perspective on issues faced by powder processes. In this section, some of the simulations possible with iGRAF will be shown with specific examples, and the type of information, evaluation and feedback that can be obtained from the simulations will be introduced for each case.

Mixing/Stirring

Mixing/stirring of multiple powder materials is one of the important processes that determine product performance. iGRAF can simulate and evaluate mixing properties of powders with different particle sizes, densities, shapes, etc.

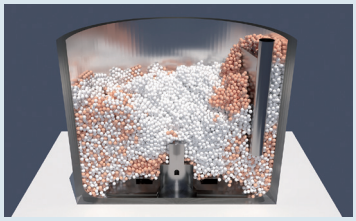
Powder Arrangement

Degree of mixing in response to the effect of initial arrangement of powder materials evaluated. Colouring according to the powder type and position provides an intuitive image of mixing, and quantitative mixing degree can be output from the dispersion state, and optimum conditions can be evaluated accurately.



Mixing Efficiency

Effect of rotation speed on the degree of mixing is evaluated and it can be seen that the degree of mixing decreases over time at high rotation speeds. Analysing the cause based on the behaviour of powder can provide useful insights for improvement.

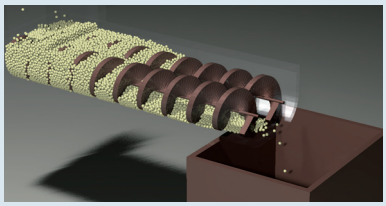


Conveyance

Proper conveyance of raw material is an essential step in powder processes. iGRAF can handle both mechanical and fluid conveyance, and possible to study the powder feed rate and conveyance mechanism.

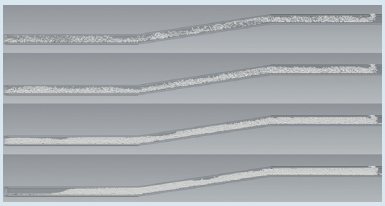
Supply Stability

Analysis of mechanical conveyance of powder by screw transport. In addition to the visualization of powder supply and conveyance process, evaluation of the conveyance volume, the force applied to the screws can also be calculated, thus possible to study specifications required for stable supply.



Blockage / Clogging

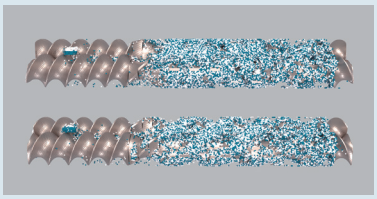
Analysis of powder conveyance by air. Can evaluate appropriate powder feed rate and conveyance air velocity. Through simulation, it is possible to verify the stability of conveyance volume being transported and blockages or clogging due to the cohesive forces between powders.



Kneading

Processes such as mixing, milling and kneading, that involves complex physics can be simulated in iGRAF.

Analysis of mixing of liquid and powder materials. Possible to evaluate the state of mixing and understand the mechanism of mixing for each part, which is difficult to verify from experiment. The combined analysis of gases, liquids and powder materials can also be used to investigate the effects of gas entrainment.

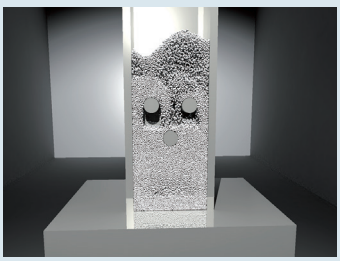


Twin-shaft kneading simulation
Kurimoto, Ltd

Fluidization

For fluidization, it is essential to consider fluids,iGRAF is equipped with functions required for this purpose.

Analysis of fluidized bed used for drying and heating powders. Through simulation, iGRAF can perform all the necessary studies for fluidised beds, such as powder behaviour, pressure drop of the fluid, powder height when fluidisation phenomena occur, optimum flow rate and inflow position, etc.

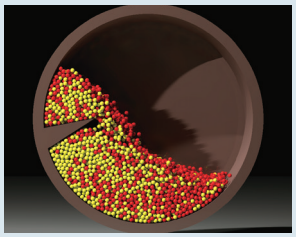


Pulverization

Milling process is one of the key unit operations used in various industrial processes. iGRAF can easily simulate milling vessels and medium-particle modifications, enabling quick and low-cost comparisons.

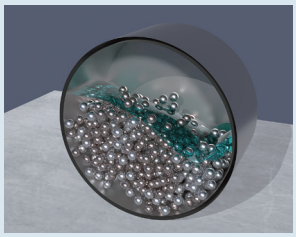
Grindability / Pulverizability

Analysis of milling with dry ball mill. Evaluating the grindability of different grinding media materials, particle size and milling speeds, based on information such as the frequency of collisions and particle velocities, it is possible to change the considerations from an empirical to a quantitative index-based study.



System Consideration

Analysis of wet milling with bead mill. iGRAF can handle the interaction between slurry (fluid) and powder particles, which is an important factor in wet milling. The impact energies of the particles and other factors enables to obtain useful knowledge for designing mills.



Storage

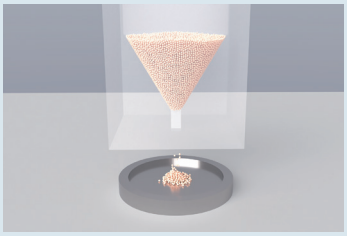
Discharge of stored powder materials is a basic operation found in many industrial processes. iGRAF can consider not only the particle size and density. but also the effect of cohesion, and it helps to understand how powder material shifts from a stationary state to a flowing state and examining discharge methods.

Segregation

Analysis of multiple powder materials being discharged from storage tank (hopper). Powder fraction in an arbitrary region can be evaluated spatially and temporally from the position of the particles, enabling the prediction of segregation and study of countermeasures against extreme segregation of specific particle sizes and types.

Bridge

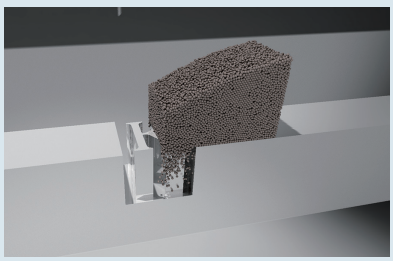
Analysis of powder material being discharged from hopper. It is possible to evaluate the feed performance in quantitative quantities required for hopper and to verify whether there is no discharge failure or bridge (blockage) due to the effects of particle size and cohesion of powder.



Filling

iGRAF can simulate parameters that affect packing, such as the balance between the gravitational and interparticle forces acting on the particles.

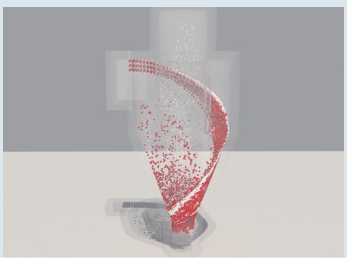
Analysis of Die filling of powder materials. It is possible to understand the filling mechanism and examine improvement plans, such as differences in the filling velocities depending on how air escapes from the die, confirming the place where powder materials are difficult to reach, and determine segregation in filling multiple powder materials.



Separation

iGRAF can handle both mechanical and centrifugal classification, as illustrated by cyclones, and can study the accuracy of classification.

Analysis of cyclone-type classifier. In addition to mechanical classification, iGRAF can also simulate classification by air flow such as cyclone can be studied. Various examination such as evaluation of classification accuracy can be evaluated for a wide range of classification systems that has different mechanisms.



User Interview

Our powder simulation software iGRAF has been utilized in a variety of applications by many users, including major companies in Japan. We would like to showcase some of the comments from our users who use iGRAF in their day-to-day work. Full text of each article can be viewed on our official website by clicking the QR code on the right.

01 Exploring the Potential of Replacing Empirical Rules with Theoretical Foundations

Eat Well, Live Well.

AJINOMOTO

Ajinomoto Co., Inc.

Enhancing Research Efficiency: Exploring Alternatives to Physical Experiments

Most of our products consist of "powders", such as seasonings, soups etc. We are working on particles design to enhance the function of the powder and the technology to control the physical properties of the powder for a better product, but in fact the behavior of powder is quite tricky. For example, if liquids are mixed, basically they are maintained at a homogeneous mixture state. Whereas for powders, it is possible for segregation to occur. As a result, the powders may not be mixed evenly and the product might need to be discarded.

Experiments are carried out in a small scale to find the solution for this issue, but it may not work well when it is scaled up for an actual machine. As a result, the experiments have to be conducted all over again, resulting in a waste of time and raw materials for the trial and error process.

At the time when I was looking for a more effective way to solve this issue, I have learned about powder simulation technology at an academic conference. With the guidance of Prof. Mikio Sakai, we considered the applicability of the simulation software to our assignment for a year. As a result, the powder simulation software iGRAF was introduced. Simulation software from other companies were also considered but iGRAF impressed us with its simple and intuitive operational method.

Other companies provided trial version and also trainings but it seemed difficult to set the simulation parameters or run the software without relying on them. On the other hand, iGRAF can be easily used by learning the software tutorials. This is why iGRAF is chosen.

Reproducibility: Embracing Flexibility and Benefits

The common processes of various powders are mixing, discharging and filling. We have started with the analysis of storing and discharging process of a hopper.

The powders that we are using are smaller than 1mm. With the simulation, we do not expect that the phenomenon to be reproduced perfectly as extremely difficult calculations are needed in order to use the original particle size. For example, cases A, B and C with different conditions are simulated to find the worst condition. If the process can be practically reproduced to find the worst condition, two-thirds of the cost of stopping the production line for testing purpose can be reduced. This is the most significant benefit of this software.

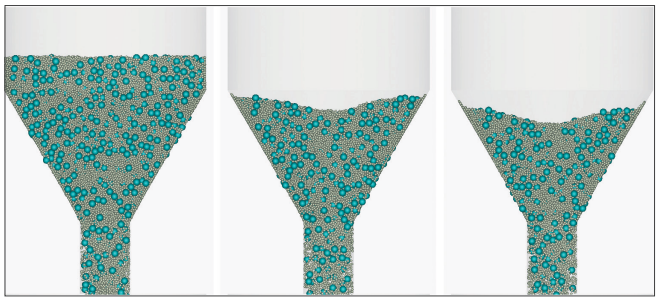
Also, if devices with different shapes are to be tested, it takes several months to produce the devices. Even the test devices are ready, experiments and analysis require time, too. With iGRAF, however, the results can be obtained within a week. Time reduction is also one of the notable benefits of this software.

Food Products Division Institute of Food Sciences and Technologies
Product Development Center Engineering Group
Ms. Sumi Yamazaki, Mr. Kazuaki Shibuki, Mr. Takeshi Nishinomiya

Harnessing iGRAF Expertise for Design Optimization and Innovation

It is known to be difficult to calculate with the actual size of the particle, but we would like to accumulate the know-how of the simulation in order to overcome it.

One of the ways to utilize the software is to solve the problems arise from the manufacturing site. Besides, we can accumulate the basic knowledge of the optimal operation conditions of the equipment that we are using. Although repeating the tests by using equipment is common in the industry, wouldn't it be better to do it at a lower cost? In other words, the decisions based on experiment experiences can be replaced by the physical theories.



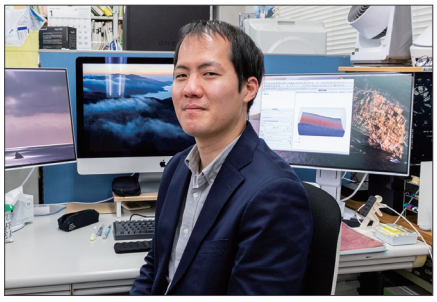
Powder discharge in a hopper
Discharge rate : 10 vol% (left), 50 vol% (middle), 70 vol% (right)

02 Ensuring the Validity of Models: Building Trust in Computational Results

National Institute of Advanced Industrial Science and Technology (AIST)

Utilizing iGRAF in Mineral Processing

Mineral processing known as ore dressing, involves crushing ore obtained from mines and separating valuable minearls from gangue minerals. Many of these processes currently rely on empirical rules. By utilizing particle simulation in mineral processing, the behavior of particles within the equipment can be visualized, leading to the development of efficient processes. We introduced iGRAF, a particle simulation software, which we believed could address our challenges, leading to its implementation.



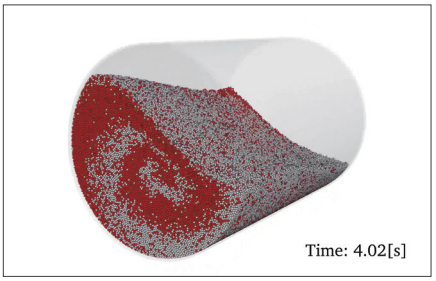
Researcher, Mineral Resources Research Group
Institute for Geo-Resources and Environment
Dr. Yuki Tsunazawa

Seamless Coupling of Particles and Fluids

iGRAF's strength lies in its ability to calculate the behavior of particles in complex-shaped equipment, a feature unique to iGRAF among other powder simulation software. It enables coupled analysis involving complex interactions between solids, gases, and liquids, which is not readily available in other software.

Furthermore, iGRAF is based on physics models developed in Prof. Sakai's laboratory and has been published in international scientific journals. The validity of the models ensures confidence in the results and allows users to understand how the calculations are performed.

We had many aspects of particle separation, involving different densities and shapes, that were still reliant on empirical rules. However, visualizing them using iGRAF enabled us to identify separation mechanisms and optimal equipment conditions. Additionally, iGRAF helped us uncover the mixing mechanism of a blending device called a pot blender, and these research findings have been accepted and published in international scientific journals.



Simulation of Pot Blender

In terms of usability, we found iGRAF to be user-friendly even for beginners. It seamlessly handles parameter input, analysis, extraction of necessary data from analysis results files, and processing them to achieve desired outcomes.

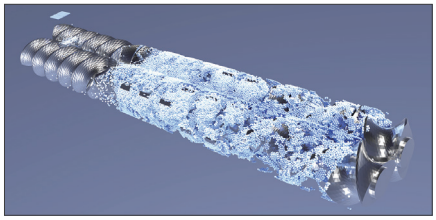
03 Bridging the Gap: Simulation Meets Reality with Remarkable Accuracy

KURIMOTO, LTD.

Qualitative Evaluation and Cost Reduction

As part of the Powder Process Technology Sales Department I belong to, we handle equipment for mixing, grinding, and drying processes. We not only provide equipment for manufacturers dealing with a wide range of powder materials, resins, and chemicals, but also propose process solutions.

Until now, we evaluated equipment performance through testing at our company's test center, which relied heavily on experience. However, this approach took time due to the need for trial and error and adjusting conditions. To address these challenges, we began considering the introduction of simulation software that could provide predictive results without the need for experiments, leading to cost savings.



Performance of Twin Screw Continuous Kneader

When we conducted simulations using iGRAF for twin screw continuous kneader , "KRC Kneader" and observed the actual behavior and were impressed by speed of calculations. Personally, I found iGRAF very user-friendly and realized that it could help solve our company's challenges. Therefore, we decided to implement it.

Successfully Designed and Manufactured a New Paddle

Based on the simulation results from iGRAF, we designed and manufactured a new paddle shape and confirmed it through visualization tests. The observed behavior matched the predicted results from the simulation, which is a significant achievement. We believe that iGRAF will become an essential tool for paddle design in the future.

Additionally, iGRAF offers high computational accuracy and the ability to display results in 3D animations, which is attractive to both us and our customers. When we show the simulation results to our customers and explain how we use iGRAF to determine paddle designs, they easily understood and are satisfied.

Powdering Process Engineering Sales Dept.
Plant Engineering & Machinery Division
Dr. Changhwa Han, Ms. Muki Sun

Moving forward, we plan to create a database of the effects of mixing conditions and residence time on the mixing state of the materials in our twin screw continuous kneader "KRC Kneader". We want to utilize this data for paddle selection before testing. Furthermore, we aim to leverage iGRAF's simulation capabilities for fluidized bed drying design. Our next step would be to apply it to grinding machines and gradually expand its usage.

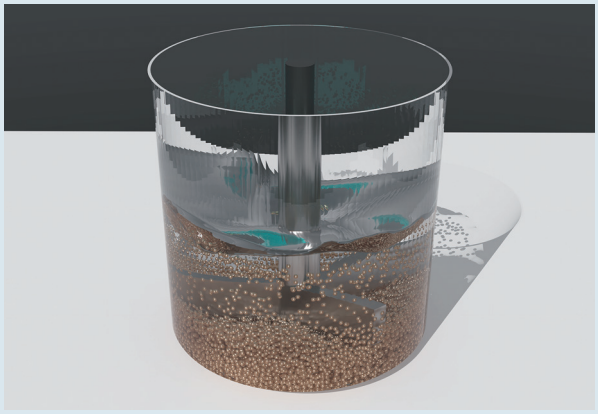
Major Physical Models and its features

iGRAF solver is equipped with various unique physical models that have been validated and published in academic journals and are compatible with elements of analysis functions of various physical phenomena, calculation stability and usability at a high level precision. Another feature is the pre- and post- processing with specialized functions for powder analysis.

DEM-CFD

Physical Model

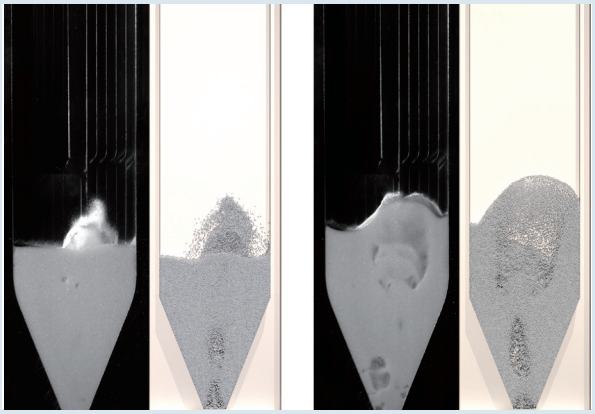
iGRAF is incorporated with a DEM solver for powder analysis and Finite Element Method solver, one of the method of CFD for fluid analysis. CFD solver in iGRAF has the analytical capability comparable to dedicated fluid analysis software, such as non-Newtonian fluids, high viscous fluids, rigid body movements and free surfaces. In addition to single-phase flows of powder and fluid, multiphase flow can be seamlessly analyzed using DEM-CFD coupled simulations.



Coarse-grained Model

Speed up

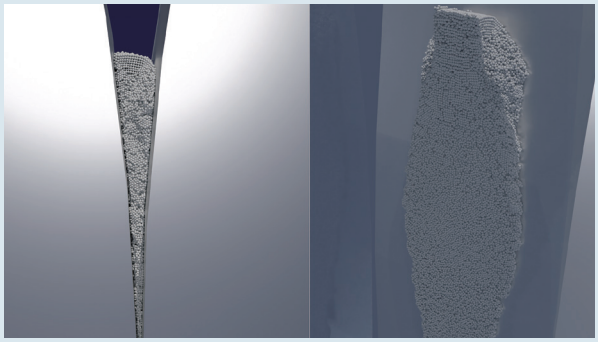
The majority of powder processes consists of a very huge number of particles and their scale has been an obstacle to simulation. iGRAF is incorporated with a uniquely developed coarse grained model that enables simulating a large-scale systems at realistic computational cost. Regarding the reproducibility of powder behavior, which is often a problem with coarse grained models, has been verified with experimental results from various systems and is validated to be a highly reliable model.



Liquid bridge force / Van der Waals force

Physical Model

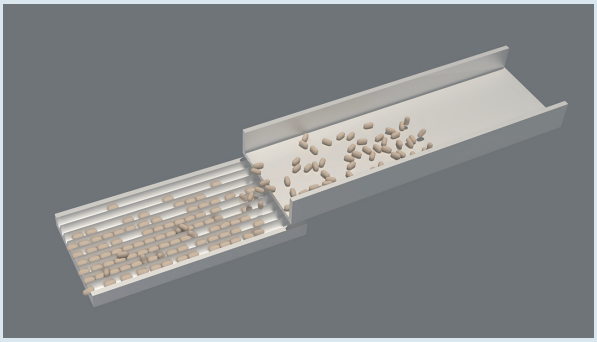
In iGRAF, liquid bridge force and Van der Waals force are considered as the cohesive forces. Liquid bridge force model, is one of the iGRAF's strength, that the model has been validated up to 15% moisture content. When the particles are small, it is known that the cohesive force acting between them with respect to gravity are dominant and models incorporated in iGRAF can reasonably predict the cohesion-dominated phenomena.



Non-spherical particle shape

Physical Model

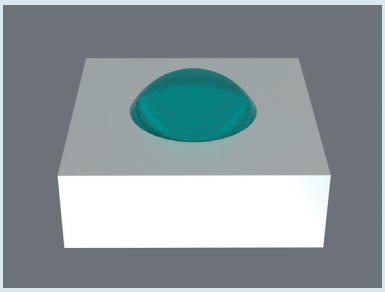
In addition to spherical shaped particles, non-spherical shaped particles can be also be considered in simulation. The non-sphericity can be chosen from parametric representation using rotational resistance model and geometric representation using a elliptical function model. Particle shapes are known to have a significant impact on the kinetic behavior of granular materials, and simulation results in high-precision reproducibility and understanding of powder behavior.



Free surface

Physical Model

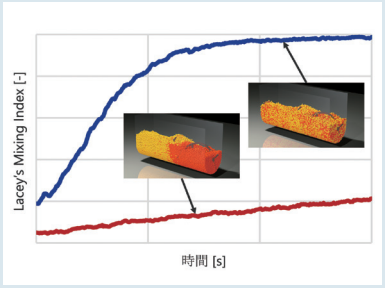
THINC/WLIC(Tangent of Hyperbola for Interface Capturing /Weighted Line Interface Calculation) method, a high-precision interface capture method based on Volume of Fluid (VOF) method, is used to analyze free surfaces where gas and liquid contact.This feature enables the simulation of powder-gas-liquid three phase flow.



Evaluation of Mixing Index

Post-process

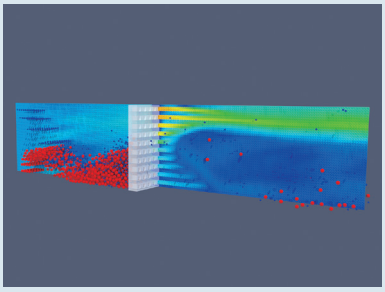
As a quantitative indicator of degree of mixing, Lacey mixing index can be evaluated. As the mixing index can be easily obtained, thus the superiority or inferiority of multiple simulation results can be judged instantaneously.The output process of the mixing index can be performed independently of the solver and can be evaluated in a short time.



Refined Grid

Speed up

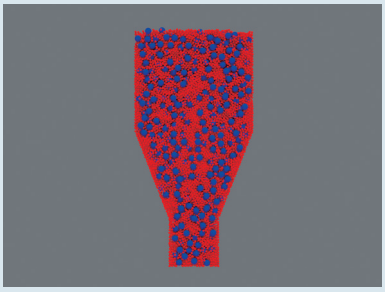
This function allows grid for fluid analysis to be set independent from the grid used for particle collision determination. Using Refined grid, required resolution of the fluid can be achieved irrespective of particle size. The computational cost can be optimized for analytical objects with narrow channels and fine geometry.



Random Arrangement of Particles

Preprocess

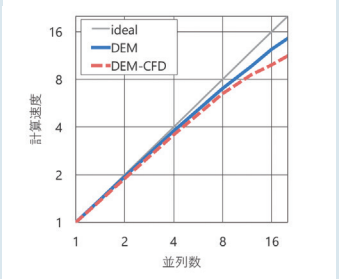
iGRAF has the ability to create an initial state, that consists of mixed state of multiple particle materials with different particle sizes and physical properties. Simulation of powder behavior from a mixed state, such as segregation, facilitated.



Parallel Computation

Speed up

Powerful solvers are essential for powder simulations. iGRAF achieves high scalability through parallel computation and optimized processing, making large scale analysis feasible on single workstation. It also supports parallel computing with Linux cluster machines, that enables the performance to be expanded to large scale simulations.



Shape Recognition

Preprocess

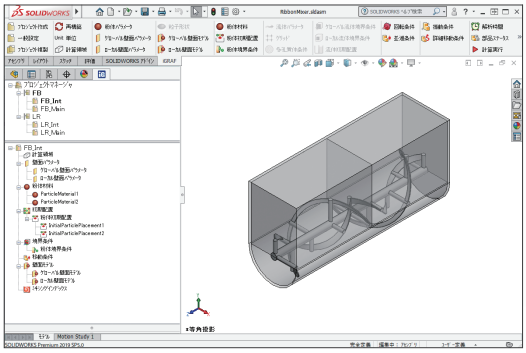
A unique method combining Signed Distance Function (SDF) and Immersed Boundary Method (IBM) used for recognition of any arbitrary geometry of solid. This enables shape recognition by orthogonal structured-grids, by enabling the simulation to be performed with simple operations without complicated mesh generation, even when the object moves.

Simulation Flow

The simulation process consists of 3 steps: pre-process, solver and post-process. One of the most time consuming pre-processing step has been designed to be easy to use even for beginners, with assistant function for complicated parameters and grid settings. The solver is powerful enough to perform real scale powder analysis without any hurdle and the post processing is equipped with a mechanism to maximize the results of the simulation, such as mixing index evaluation that is unique in iGRAF.

Step1 : Pre-process

Pre-processing includes model creation / import, setting of analysis conditions such as physical properties of powder / fluid and machine operating conditions.



Information required to carry out simulation

●Machine Information
Machine geometry / Operating condition (operating hours, rotational speed, flow rate, etc.)

●Particle Information
Particle size distribution / True density / Loose bulk density / Firm bulk density / Powder volume / Angle of repose / Other characteristics (shape, moisture content, etc.)

●Fluid Information
Density / Viscosity / Surface tension / Contact angle

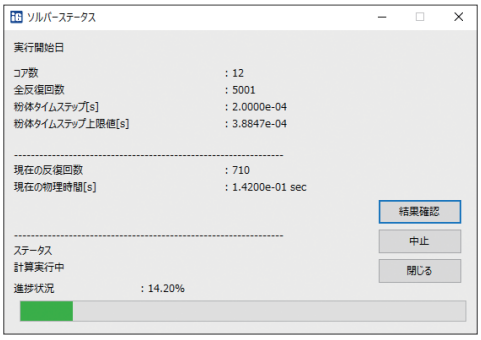
Model Creation
Create 3D CAD model
(SOLIDWORKS Add-in version only)

Analysis condition setting
Setting of powder and fluid parameter, initial arrangement setting, operating condition

Grid setting
Grid width setting

Step2 : Solver

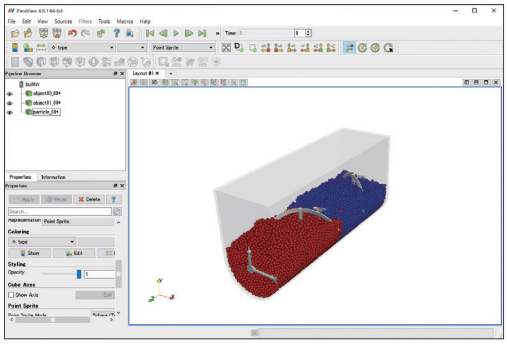
Based on the geometry data and analysis condition set in the pre-processing, the calculation are performed. With the solver status, the progress of the calculation can be monitored in real-time. In addition, high-speed computation can also be achieved with parallel computation for large scale calculation targets.



No.of cores to use ▶ Run Simulation

Step3 : Post-process

Post processing visualizes the output data from the solver. In addition to the graphical representation of velocity and pressure, numerical data such as torque, pressure drop and mixing index evaluation can be exported.

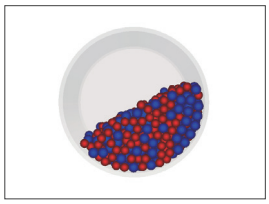


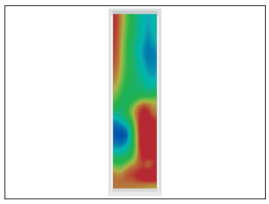
Processing of result

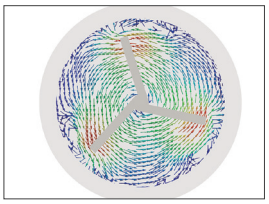
Visualization / Image and Video export / Time history data export

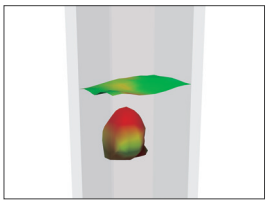
Result export method

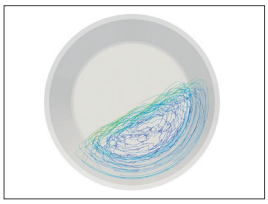
Powder movement / Contour / Vector / Iso surface / Trajectory / Particle data / Data extraction from area of interest / CSV / Snapshot / Animation


Powder movement


Contours


Vectors


Isosurface


Particle trace

List of features / Operating environment

Pre	CAD interface	SOLIDWORKS
	Grid generation	Particle grid / Fluid grid (Refined grid)
	Project	Multiple project management, Project clone
	Others	Recommended Time step auto calculation
Solver	Analysis Type	Powder single phase (DEM), Fluid single phase (CFD), Powder-gas phase (DEM-CFD), Powder-liquid phase (DEM-CFD), Gas-liquid phase (CFD-VOF), Powder-liquid-gas (DEM-CFD-VOF)
	Particle arrangement	Regular arrangement (No. of particles, Weight), Random arrangement (Particle size distribution)
	Powder-Powder and Powder-Wall interaction force	Van der Waals force, Liquid bridge force, Lubrication force, Coefficient of restitution, Coefficient of friction, Rotational resistance, heat transfer
	Particle shape	Spherical shaped, Non-spherical shaped (ellipsoidal function model / rotational resistance model), different particle size and density mixtures, free-form particles
	Powder Boundary Condition	Spring constant, Coefficient of restitution, Coefficient of friction, Coefficient of rotational resistance, contact angle, flow velocity
	Mixing Index Evaluation	Lacey's Mixing Index
	Fluid	Newtonian fluid, Non-Newtonian fluid, High viscous fluid model
	Turbulence Model	LES (Smagorinsky model)
	Wall Boundary Condition	Wall surface, Flow velocity, Pressure specification
	Free surface	Volume of fluid method
	Rigid body motion	Rotation, Translation, Vibration, Enhanced motion such as acceleration, deceleration can be specified (CSV file input)
	Shape Recognition	Signed Distance Function (SDF), Immersed Boundary Condition (IBM)
	Analysis Execution	Parallel computation, Interrupted computation, Batch analysis
	Reduction of computational load	Coarse grain ratio, Porous medium condition
	Project Connection	Result can be transferred from project A to set as the initial state of project B
Post	View	Particle distribution, contour, vector, iso surface, streamline Powder representation, Cross sectional view, representation of region of interest by threshold value
	Result processing	Extraction of particle data, extraction of data from region of interest
	File Export	Snapshot, Animation, CSV file
Operating Environment	OS	Windows 10, Windows 11
	CAD	SOLIDWORKS 2018, 2019, 2020, 2021, 2022, 2023
	ParaView	Ver. 4.0.1
	CPU	More than 6 core
	Memory	More than 16GB
	GPU	SOLIDWORKS recommended specifications

Services

Software sales / Implementation & Operational support

Customization

Consulting Project (Service avaliable for Japan)

Technical Support

We are working to promote and expand the use of powder simulation technology.

Kozo Keikaku Engineering Inc. serves as the representative secretary of the Powder Simulation Technology Application Subcommittee and vice-chairman of the AI Technology Application Committee of the Japan Powder Industry Technology Association, and is working to solve various problems in the industrial world that deals with powders and to promote the use of powder simulation technology through initiatives such as software development, hosting events and introducing examples of use at symposium and other events.

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You can also find out more about iGRAF on the product website here.

iGRAF Website
https://www.sbd.jp/products/powder/igraf.html