QUANTITATIVE MIXING ANALYSIS OF LAMINAR FLOW IN STATIC MIXER WITH SPACE FILLING CIRCLE GRID PERFORATED PLATE

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ABSTRACT

The applications of the static mixers are widely applied in many industries to obtain the desired type of mixing. In this context, to perform the mixing process should have two different fluids that also have different properties which will combines it in a single equipment to make an another fluid. The main objective of this research study is to propose a new approach of fractal concept (circle grid perforated plate) for internal rapid mixing by determining the coefficient of variation (COV). This study was implemented by fully numerical simulations. The simulations of mixing fluid were carried out with the help of commercial computational fluid dynamic (CFD) package ANSYS CFX 14.0 software. The simulation was done primarily in cylindrical pipe with insertions of circle grid perforated plate with porosity of 50% and 75%. Three levels of laminar flow have been chosen to result in Reynolds numbers (Re) equal to 100, 200 and 400. The effectiveness of circle grid perforated plate static mixer has been evaluated by comparing the homogeneity level of mixing fluids to the Kenics static mixer that readily available in industries applications. Based on the research findings, the COV value of circle grid perforated plate with 75% porosity at Reynolds number 400 is 0.00427 which is almost completely mixed for mixing fluid and the pressure drop value is 6.021kPa. In term of manufacturing cost and energy loss due to static mixer, definitely this new approach of 75% porosity circle grid perforated plate is better design compared to the Kenics static mixer because of lower number of inserts and simpler design of static mixer to produce.

ABSTRAK

Aplikasi melibatkan *static mixer* digunakan secara meluas dalam banyak industri untuk mendapatkan jenis campuran yang dikehendaki dalam sesuatu produk. Dalam konteks ini , untuk melaksanakan proses pencampuran perlu mempunyai dua cecair yang berbeza yang juga mempunyai ciri-ciri yang berbeza yang akan bercampur dalam satu alat yang sama untuk menghasilkan jenis cecair yang dikehendaki. Objektif utama kajian penyelidikan ini adalah untuk mencadangkan satu pendekatan baru konsep fraktal (*circle grid perforated plate*) untuk pencampuran pesat dalaman dengan menentukan pekali varians (COV). Kajian ini dilaksanakan oleh simulasi komputer sepenuhnya. Simulasi pencampuran cecair telah dijalankan dengan bantuan komersial perkomputeran dinamic bendalir (CFD) pakej perisian ANSYS CFX 14.0 . Simulasi tersebut telah dilakukan terutamanya dalam paip silinder dengan sisipan grid bulatan piring dengan keliangan sebanyak 50 % dan 75 %. Tiga peringkat aliran lamina telah dipilih untuk menyebabkan nombor Reynolds (Re) sama dengan masing-masing 100, 200 dan 400. Keberkesanan *circle grid perforated plate static mixer* telah dinilai dengan membandingkan tahap kehomogenan yang mencampurkan cecair dengan *Kenics static mixer* yang sedia ada digunakan dalam industri. Berdasarkan kajian ini, nilai COV untuk *circle grid perforated plate static mixer* dengan 75 % keliangan pada nombor Reynolds 400 adalah 0.00427 yang hampir sepenuhnya bercampur bagi dua jenis cecair berlainan ciri-ciri dan nilai kejatuhan tekanan adalah 6.021kPa . Dari segi kos pengeluaran dan kehilangan tenaga disebabkan *static mixer*, pasti pendekatan baru ini yang mana *circle grid perforated plate static mixer* dengan 75 % keliangan adalah reka bentuk yang terbaik jika dibandingkan dengan *Kenics static mixer* kerana jumlah *insert* yang lebih rendah dan reka bentuk yang mudah dihasilkan.

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LIST OF SYMBOLS AND ABBREVIATIONS

D_h	-	Hydraulic Diameter
F	-	Fanning Factor
L	-	Length of the Tube
N	-	Number of data points
Δp	-	Pressure Drop
v	-	Velocity of fluid
Re	-	Reynolds Number
ρ	-	Density of Fluid
x_i	-	Each of the Data Values
$\bar{x}$	-	The mean of the x_i
σ	-	Standard Deviation
μ	-	Dynamic Viscosity
COV	-	Coefficient of Variation
CFD	-	Computational Fluid Dynamics

CHAPTER 1

INTRODUCTION

1.1 Fluid Mixing Process

Today, mixing is one of the important processes to the many industries. Fluid mixing process typically involves three phases of fluid in the form of liquids, gases and solids. Besides that, to obtain the desired type of mixing, it can be done by using either static mixers or mechanically stirred vessels. Static mixer is a device that has the mixing element which consists of stationary inserts that is installed in pipe or transfer tubes. The stationary inserts are used to redistribute fluid in a direction of the main flow for radially and tangentially. For a simple mixing in our daily lives is as easy as mixing water with sugar in a glass. In this context, to perform the mixing process should have two different fluids that also have different properties which will combines it in a single equipment to make an another fluid. The applications of static mixers are used in variety of processes such as blending of miscible fluids both in laminar and turbulent flows, mixing and dispersion of immiscible fluids by helping to generate an interface, solid blending, heat and mass transfer and homogenization (Etchells III A.W., 2004).

Basically, the applications of the static mixers is widely applied in many industries such as petrochemical and refining, chemical and agricultural chemicals production, minerals processing, grain processing, food processing, pharmaceuticals and cosmetics, polymers, plastics, textiles, paints, resins and adhesives, pulp and paper, water and waste water treatment.

The static mixers are used in continuous processes as an alternative way to conventional agitation since similar and sometimes better performance can be achieved at lower cost. The static mixers have not involved in moving parts and at the same time it will have lower energy consumptions, smaller space requirements, low equipment cost and reduced maintenance requirements compared with mechanically stirred mixers. They offer a more controlled and scale able rate of dilution in fed batch systems and can provide homogenization of feed streams with a minimum residence time. They also provide good mixing at low shear rates where locally high shear rates in a mechanical agitator may damage sensitive materials. Static mixers also come with self cleaning features. Interchangeable and disposable static mixers are also available. (Etchells III A.W., 2004)

The energy needed for mixing comes from a loss in pressure as fluids flow through the static mixer. There are varieties of static mixers that have been proposed. One design of static mixer is the plate-type mixer and the other device consists of mixer elements contained in a cylindrical (tube) or squared housing. Mixer size can vary from about 6 mm to 6 meters diameter. Commonly, the fabrication materials for static mixer components included stainless steel, Teflon, polypropylene, polyacetal, PVDF, PVC and CPVC (Albright, 2008). According to Thakur R. K. (2003), they report that existence of approximately 2000 US patents and more than 8000 literature articles that describe static mixers and their applications. They are several types of static mixers that commercially available such as Kenics mixers, KMS and SMX that are used in both laminar and turbulent flow regimes to achieve thermal homogenization of polymer melt. (Chen, 1975)

1.1.1 Basics of the Mixing Technology

1.1.1.1 Homogenising

Homogenising in the mixing technology is mixing certain inter-soluble liquids up to a certain homogenizing degree (mixing quality) or the up-keep of the homogeneity for a certain reaction. The liquids to be mixed may be differ for instance in concentration, colour or temperature. The time period needed for mixing is the homogenizing time. (Hintz, 2008)

1.1.1.2 Suspending

Suspension is the even distribution of solid particles in a liquid (homogeneous mass). The mixer avoids sedimentation of the solid particles in the liquid. A mixture of solid particles and liquids subjects the mixing equipment to excessive wear, which is proportional to the third power of the circumferential speed (tip speed) of the mixing tool. It is therefore recommend that the speed be kept to the barest minimum. This is often also advantageous to the product. (Hintz, 2008)

1.1.1.3 Dispersing

Dispersing is the mixing process of two liquids which normally are insoluble. The drops ($\geq$ 1µm) of the dispersing phase are spread over the continuous phase. Dispersions are unstable and demix when the power is too low or lacking totally. The actual task of dispersing is the enlargement of the phase border line so that for instance the process of chemical reaction is faster. (Hintz, 2008)

1.1.1.4 Gasification

The result of the gasification of liquids is the enlargement of the phase border line between liquids and gas. Generally the liquid is the continuous phase (coherent phase) and the gas is the disperse phase (divided phase). Basically one differentiates between self and uncontrolled gasification. With the practical application, which is foremost the uncontrolled gasification, the gas is pumped through a ring shower into the vessel, the stirring tool crushes the gas flow into small bubbles and divides them in the liquid. (Hintz, 2008)

1.1.1.5 Heat Exchange

A controlled heat transfer is very essential in many processes. Due to an unfavourable ration of heat transfer areas to the vessel volume only very little heat per time unit can be transferred. Improved heat exchange can be obtained through a suitable mixing tool. Its function is to produce a flow along the heat transfer areas (vessel jackets) such as to improve the heat transfer coefficient and thereby the heat transit coefficient. (Hintz, 2008)

1.1.2 Characterization of Particle Mixtures

Julio De Paula et al. (2002) stated that, based on chemistry study a mixture is not combined chemically and the material just mix by two or more different substances. A mixture refers to the physical combination of two or more substances on which the identities are retained and are mixed in the form of suspensions, solutions and colloids. Mixtures are the chemical substances that are mixed by mechanical blending or mixing in order to produce a specific product. The chemical substances have fully transformed to the specific product without chemical bonding or other chemical change. So, each of the chemical substances retains its own chemical properties.

Gy. (1979) found that mixtures can be either homogeneous or heterogeneous. A homogeneous mixture is a type of mixture that every part of the solution has the same properties and composition is uniform. A heterogeneous mixture is a type of mixture that have two or more phases present in the components which can be seen. For example, air is a homogeneous mixture of the gaseous substances nitrogen, oxygen, and smaller amounts of other substances. Salt, sugar, and many other substances dissolve in water to form homogeneous mixtures. Cereal in milk is an example of a heterogeneous mixture.

1.1.2.1 Characterization of Mixing States of a Granular or Particular Material

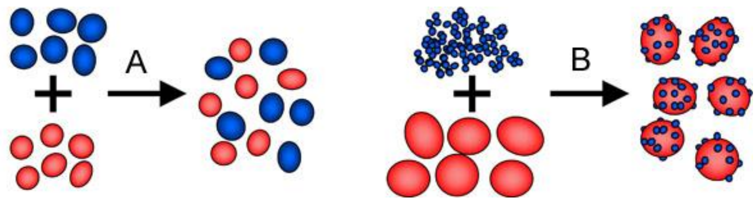


Figure 1.1: Types of mixture in mixing states: (A) Random mixture; (B) Interactive mixture. (Bridgewater, 1976)

Figure 1.1 shows the types of mixture in mixing states that usually find in mixing process. It can be either random mixture or interactive mixture. A random mixture can be occurred if two different free-flowing substances of approximately the same particle size, density and shape are mixed. This type of mixture only occurs when the particles are not cohesive and do not cling to one another. The quality of the random mixture also depends on the mixing time. However, segregation can occurs if the substances consist of different particle size, density or shape. The segregation can cause separation of the mixture (Bridgewater, 1976). The second type of mixture is ordered mixture. It is first introduced to describe a completely homogeneous mixture. However, a completely homogeneous mixture is only achievable in theory and other denotations were introduced later such as adhesive mixture or interactive mixture (Hersey, 1975). The third type of mixture is interactive mixture. It can be obtained if a free-flowing substance is mixed with a cohesive particle. The cohesive particles adhere to the free-flowing particles to form interactive units. In practice a combination of a random mixture and an interactive mixture may be obtained which consists of carrier particles, aggregates of the small particles and interactive units (Staniforth, 1981).

1.1.2.2 Process Principles for Input of Mechanical Energy into Particulate Systems.

Berk, (2009) stated that the prime objective of mixing is to have homogeneity (uniform distribution) in the product. The homogenization of the mixture usually is done by the reduction of particle size achieved by the action of shearing forces. The effective energy input by unit mass or unit volume fluid will affect the quality of mixing. The important power correlations in the field of mixing are the power number, Reynolds number and Froude number. These correlations will help to know deeply on the forces taking place in each case of mixing, relating the dimensions, type and operating conditions. The Reynolds number is a very important parameter because it helps to understand the flow regime. The Froude number contains the gravitational forces, the Reynolds number describes the inertial and viscous forces and the power number relates the power (torque) with the diameter of the impeller, speed shaft and density of the liquid. Table 1.1 shows the types of mechanically mixing process that usually applied in industries which require mechanical energy in order to mix of the substances. Each of the mixing process can be applied for certain substances or materials depend on the homogeneity level that is required to produce specific product in certain applications.

Table 1.1: Type of mixing process (Hintz, 2008)

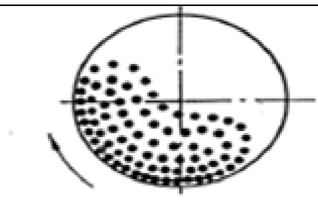
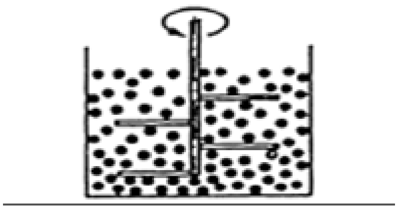
Process principle	Schematic sketch	Example
Rotating process chambers or vessels		Drum mixer, drum mill, drum dryer
Agitated systems		Mechanical silo discharging, forced mixing, impact mill

Table 1.1(continued): Type of mixing process (Hintz, 2008)

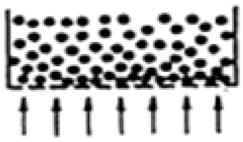
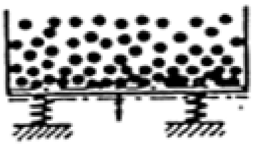
Flow of fluids through granular beds		Pneumatic silo discharging, pneumatic homogenization, fluidized beds
Vibrations		Vibration systems for charging and discharging, screen machine, vibration mill

Figure 1.2: Horizontal drum mixer (Agratechniek, 2009)

Figure 1.2 shows one type of the mixer which is horizontal drum mixer that consist inner blades. The horizontal drum mixer operates as the material flows through the inlet opening into the mixing chamber. The mixing process will be started when the entire product is loaded and slips over the inner blades. This type of mixer has no stationary segments which not deal with risk of separation. All components are continuously and randomly picked up and moved through the drum. After the mixing time the valve opens and mixing chamber will be discharged automatically. (Agratechniek, 2009)

1.2 Research Background

Nowadays, mixing operations are essential in the process industries. They include the classical mixing of miscible fluids in single phase flow as well as heat transfer enhancement, dispersion of an immiscible organic phase as drops in a continuous aqueous phase, three-phase contacting and mixing of solids. Static mixer have been applied to all this applications including liquid-liquid systems (extraction), gas-liquid systems (absorption), solid-liquid systems (pulp slurries) and solid-solid systems (solid blending). Static mixers are now commonly used in the chemical and petrochemical industries to perform continuous operations.

The effectiveness of static mixers for the miscible fluid or to enhance heat transfer is due to their ability to perform radial mixing and to bring fluid elements into close proximity so that diffusion or conduction becomes rapid. In laminar flows, static mixers divide and redistribute streamlines in a sequential method by using only the energy of the flowing fluid. In order to design optimal mixer geometries, appropriate tools and methods are needed to characterize the flow conditions and their influence on the mixing process. In addition, concentration distributions were determined as an essential measure of homogeneity level. A widely used measure for presenting the uniformity of concentration at a cross section of static mixer is the coefficient of variation (COV). The COV is defined as the standard deviation of concentration over the mean concentration for a given set of N data points. The data used to calculate the COV are taken from volume fraction at the specific cross section planes of interest in this study.

1.3 Problem Statement

A static mixer is one of devices in engineering industries that is used for the continuous mixing of fluid materials. Generally, static mixer is used to mix liquid, but it can also be used to mix gas streams, disperse gas into liquid or blend immiscible liquids. The loss in pressure as fluids flow through the static mixer is used as energy for mixing in pipelines. There are several benefits of static mixer compared to other types of mixer such as low energy consumption, low investment costs, minimum space requirement, prompt delivery time, no moving parts thus robust and maintenance free, tanks and agitators are not needed because of inline production process and easy to install in piping system also no special knowledge needed.

In industry, there are many types of static mixer have been designed and it is used widely in industry. However, there are many static mixers that have been proposed in industry having complex and complicated in design. The type of static mixer that usually used in industry is Kenics, SMX, SMI, SMV, KVM and Compax Static Mixer. Each of static mixers has their own arrangement and shape of mixer that is designed in order to get better efficiency to mix the fluid homogeneously. At the same time, each of the design requires high cost of manufacturing and need to spend a lot of time in manufacturing and installation.

This research study will come out with simple design of static mixer and at the same time having standard efficiency of mixer in order to reduce current cost of manufacturing but still producing same results of mixing fluid as other static mixers. In order to design optimal mixer geometries, appropriate tools and methods are needed to characterize the flow conditions and their influence on the mixing process. In this study, COV will be applied in order to measure for presenting the uniformity of concentration at a cross section of static mixer. The simulation of mixing fluid can be simulated by using computational fluid dynamic (CFD) software. The simulation will predict the behaviour of the fluid flow in pipeline flow through the static mixer. This study will focus on simulation of fluid flow after the fluid flow through the static mixer at specific distance of interest. The efficiency of static mixer can be measured by observing the behaviour of volume fraction at outlet sections after the fluids pass through several insert numbers of static mixers.

1.4 Research Objective

This research study embarks on the following objectives:

1) To propose a new approach of fractal concept (circle grid space filling fractal) for internal rapid mixing by determining the coefficient of variation (COV).
2) To assess a capability of fractal pattern in mixing process.
3) To make a recomendation for new concept of static mixer in pipe flow by using a fractal concept based on space filling circle grids fractal.

1.5 Scopes of Study

To conduct this research study, several scopes have been outlined:

1. The simulation is done primarily in cylindrical pipe with insertions of perforated plate to make it functioning as static mixer.
2. The perforated plate with circle grid pattern which porosity of 50% and 75% will be applied.
3. Three levels of laminar flow will be chosen to result in Reynolds numbers (Re) equal to 100, 200 and 400 respectively.
4. This study will be implemented by fully numerical simulations.
5. In order to test the quality of the new modelling approach, the numerical simulations will be done by comparing their results of volume fraction with previous simulation of Kenics mixer to evaluate local values of mixing degree.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews on the literature such as journals, books, website and articles that related to the mixing analysis of laminar flow in static mixer with space filling circle grid perforated plate. This literature review will cover on:

2.1 Reviews on concept and mixer working principle of static mixer.
2.2 Reviews on Computational Fluid Dynamic (ANSYS Software).
2.3 Reviews on previous research which related to the case study.

2.2 Characteristics and Concept of Static Mixer

2.2.1 Fractal Pattern

According to Mandelbrot (2004), a fractal is a mathematical set that has a fractal dimension that usually exceeds its topological dimension and may fall between the integers. Basically, the fractals have self similar pattern which means it has same pattern from near and far position. It has exactly the same pattern whether it use a different scales. It is the idea of pattern which having detailed pattern repeating itself and infinite. The term "fractal" was first used by mathematician Benoît Mandelbrot in 1975. The fractal have been taken based on the Latin frāctus meaning "broken" or "fractured", and used it to extend the concept of theoretical fractional dimensions to geometric patterns in nature. (Mandelbrot, 2004)

Generally, the way on how to define fractal concept have some disagreement amongst authorities. But, the majority people who have studied about fractal concepts agree that theoretical fractals are infinitely self-similar, iterated, and having fractal dimensions with detailed mathematical constructs. The fractal concept is not just about geometric pattern, but it also can describe processes in time. Based on the fractal concept, it is extensively studied about various degrees of self-similarity such as structures, image, technology, art, law and nature. The fractal pattern can be modelled which considering of physical time and space.

2.2.1.1 Koch Curve

The curve of Von Koch is one of the applications of fractal concept which is generated by a simple geometric procedure. This simple geometry can be iterated an infinite number of times by dividing a straight line segment into three equal parts and substituting the intermediate part with two segments of the same length.(Riddle, 2013)

Ideally the iteration process should go on indefinitely. Nevertheless, when the elementary side becomes less than the pitch, there are no longer changes of display. So, the iteration will stop as well. The total length of the Koch Edge can be maintained by multiplying the length of the size with 4/3 each of iteration in order to get constant distance for each segment. So, the length of the curve after n iterations will be $(4/3)^n$ times the original triangle perimeter.

2.2.1.2 Koch Snowflake

According to Poitevint (2003), the Koch snowflake usually called as the Koch star and Koch Island is a mathematical curve and one of the earliest fractal curves to have been described. It is based on the Koch curve, which appeared in a 1904 paper titled "On a continuous curve without tangents, constructible from elementary geometry" by the Swedish mathematician Helge von Koch.

Other than Koch snowflake, the fractal concept had been derived to develop more pattern concepts. The sierpinski carpet is a plane fractal first described by Wacław Sierpiński in 1916. The sierpinski carpet begin with a square. The square is cut into 9 congruent subsquares in a 3-by-3 grid, and the central subsquare is removed. The same procedure was carried out to present the pattern same as Figure 2.1(a) (Wikipedia, 2013). According to the sierpinski carpet concept, circle grid fractal pattern had been developed by using turtle graphic as shown in Figure 2.1 (b). (Programming, algorithms, coding in practice, 2012

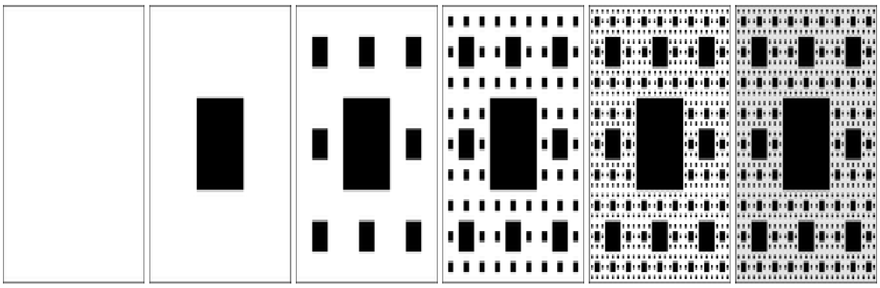


Figure 2.1(a): Variant of Sierpinski Carpet Fractal Concept (Wikipedia, 2013)

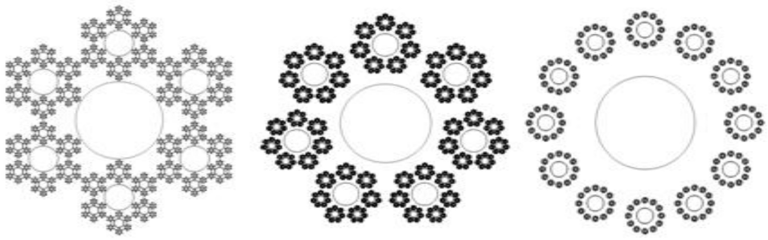
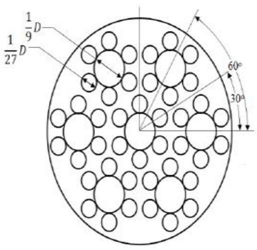


Figure 2.1(b): Circle Grid Fractal Pattern (Programming, algorithms, coding in practice, 2012)

2.2.1.3 Mathematical Formulation for Geometry of the Circle Grids Space Filling Plate

According to Bukhari Manshoor (2012), circle grids space filling plate has two grades of holes which different dimension, as described in Figure 2.2. The smaller holes are concentrated near the plate edge because the major concentration of eddies and swirl is near the wall. On the other hand, this radial reduction of holes diameter assists in stabilizing the velocity distribution. The geometry of holes is expressed in terms of plate diameter. The geometry of circle grids space filling plate basically come from the idea of fractal pattern with specific ratio has been defined. (Bukhari Manshoor, 2012)



Hole grade	Number of holes	Hole diameter
1	7	0.111D ±0.002 D
2	42	0.037D ±0.002 D
Standard plate thickness		$0.12D \leq t_p \leq 0.15D$
Standard upstream pipe length		$17D \leq L_f$
Standard downstream pipe length		$7.5D \leq L_s \leq L_f - 8.5D$

Figure 2.2: Description of circle grids space filling flow conditioner plate (Bukhari Manshoor, 2012)

According to G. Coppola (2009), blockage ratio is defined as ratio of the area blocked by the grid to the whole area of the channel/tunnel square or circle section before it become turbulent or laminar flow. Blockage ratio can be opposite meaning with porosity which porosity means the holes area of the channel/tunnel square or circle section. It can be easily described by percentage value of blockage ratio or porosity.

2.2.2 Static mixer and working principle

According to Charles Ross, in the process industries, static mixers or motionless mixers are the standard equipment that is usually used for fluid mixing process. The application of static mixers is inline in a once-through process or as supplement or replace a conventional agitator. Generally, the static mixers are suitable used in continuous processes where as alternative to conventional agitation. At lower cost, it might be similar or sometimes give better performance than conventional agitation. Furthermore, static mixers have no moving parts that will affect to the lower energy consumptions and reduced maintenance requirements. They are available in most materials of construction. (Charles Ross)

In industries, static mixers have been applied in wide range of process operations such as laminar flow heat exchange, dispersion and emulsion formation. Basically, static mixers has been tested and trusted in many different industries for combining liquids, gases and powders. The mixing process can be done by continuous splitting, extension and transportation of the components. Differences in concentration, temperature and velocity are equalized over the flow cross-section. They are manufactured in a wide range of materials, including carbon steel, stainless steel, exotic alloys, Glass-reinforced plastic (GRP), Unplasticized Polyvinyl chloride(uPVC),Chlorinated polyvinyl chloride (cPVC) and Polytetrafluoroethylene (PTFE).

The static mixers are made in various designs which are fitted into a range of housings in order to apply for different applications in industries. It can be either fixed or removable which has several numbers of static mixers that depends on the required homogeneity level. There are some advantages of static mixers as mixing elements for the industries application. Static mixers deliver a high level of mixing efficiency, therefore the consumption of dosed chemicals and formation of by-products can be dramatically reduced. It has highly efficient mixing with low energy consumption and at the same time will replace the equipments such as tanks, agitators, moving parts and direct motive power to the simpler mixing elements.

The energy required for mixing is efficiently extracted as pressure drop from the fluid flow through the elements. Mixers are invariably installed in existing systems without reducing the capacity of existing pumps. The installation is very easy and no special skills are required other than normal engineering skills. Static Mixers are available in all standard pipe sizes and in the case of open channel designs are available in any size with no upper limit. Each Static Mixer is carefully designed to meet the specific requirements of each application. (Thottam)

2.2.2.1 Principles of operation

According to Lenntech (2012), there are three simple cases of mixing operation which depends on the type of flow and liquids. The first case is two miscible liquids in laminar flow which the main mechanism in a static mixer is flow division. The elements split the fluids entering in two streams and then rotate them through 180 degrees. The elements are arranged in a series of alternating left and right hand 180 twists. The elements are in series in the mixer. As the number of streams or layers increases, the layer thickness decreases. Normally, 12 to 24 elements are required to provide a complete mix.

The second case is two miscible liquids in a turbulent flow which the main mechanism is radial mixing. The fluids are continuously moving from the pipe centre to the pipe walls and the fluid change direction with each succeeding element. Normally, a fully homogeneous mix in a turbulent flow requires about 1.5 to 4 elements.

The third case is two immiscible liquids in a turbulent flow which the radial mixing mechanism reduces radial differences in velocity and in droplet sizes. It will increase the surface area of contact between phases, improving the mixing. The disperser length necessary depends on the required contact time. For mass transfer processes in which equilibrium is quickly established, a length of 5 diameters is generally sufficient. (Lenntech, 2012)

2.2.2.2 Types and Applications

According to Lenntech (2012), static mixers provide the highest standard of mixing efficiency, reliability and economy for thousand of process plants worldwide. The static mixers can be categories in group such as channel mixers, pipe mixers and gas dispersion systems.

i) Channel mixers:

It is installed in new treatment works in existing installations. They rapidly achieve a high degree of mix with extremely low head loss on very short lengths. Channel mixers cover a wide range of flow rates and are ideal for efficient chemical dosing. They allow chemical savings with consequently economical and environmental savings. Figure 2.3(a) shows the one of the channel mixer.

ii) Pipe Mixers:

The range of materials of mixer can be in stainless steel, PVC, Polypropylene (PP) and carbon steel. It can be fixable or removable. It is available with heating and cooling jackets, injectors, sample points and instrumentation bosses. It is suitable for all industries. It has wide range of diameters which is from 10 to 300 cm. Figure 2.3(b) shows the one of the channel mixer.

iii) Gas Dispersion systems:

It uses two different mixers which one of the mixers is used to form gas bubbles and the second to provide contact time and efficient mass transfer.

(a) **(b)**

Figure 2.3: (a) Statiflo Channel and (b) pipe mixers (Lenntech, 2012)

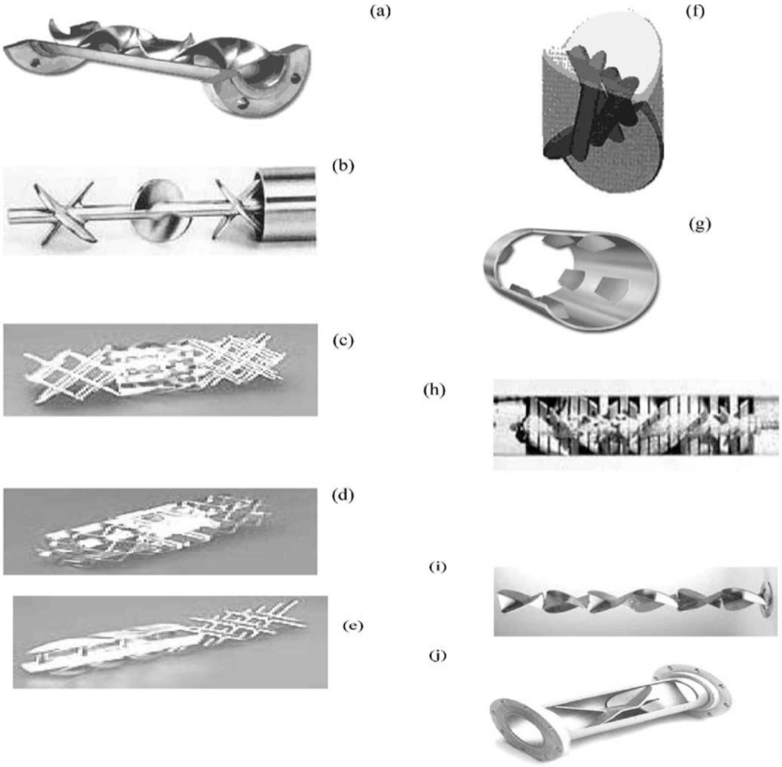


Figure 2.4: Elements of different commercial static mixers:

(a) Kenics (Chemineer Inc.); (b) low pressure drop (Ross Engineering Inc.); (c) SMV (Koch-Glitsch Inc.); (d) SMX (Koch-Glitsch Inc.); (e) SMXL (Koch-Glitsch Inc.); (f) Interfacial Surface Genera;(g) HEV (Chemineer Inc.);(h) Inliner series 50 (Lightnin Inc.); (i) Inliner series 45 (Lightnin Inc.); (j) Custody transfer mixer (Komax systems Inc.); (Thakur et al. ,2003)

According to Thakur et al (2003), Figure 2.4 shows the several types of static mixer that are readily available in market for industries application. Table 2.1, 2.2 and 2.3 show the companies that have designed each of the static mixers, the capability of static mixer in specific area of applications.

Table 2.1: Commercially available static mixers (Thakur et al. ,2003)

Company	**Mixers**
Chemineer-Kenics	Kenics mixer (KM), HEV (high efficiency vortex mixer)
Koch-Sulzer	Sulzer mixer SMF, SMN, SMR, SMRX, SMV, SMX, SMXL
Charles Ross & Son	ISG (interfacial surface generator), LPD (low pressure drop), LLPD
Wymbs Engineering	HV (high viscosity), LV (low viscosity)
Lightnin	Inliner Series 45, Inliner Series 50
EMI	Cleveland
Komax	Komax
Brann and Lubbe	N-form
Toray	Hi-Toray Mixer
Prematechnik	PMR (pulsating mixer reactor)

Table 2.2: Industrial applications of commercial static mixers (Thakur et al. ,2003)

Mixer	**Flow regime**	**Area of application**
Kenics	Laminar/turbulent	Thermal homogenization of polymer melt Gas–liquid dispersion
	Turbulent 980<Re<8500	Dilution of feed to reactor Dispersion of viscous liquids Enhancement of forced flow boiling heat exchanger
SMX	Laminar	Mixing of high viscosity liquids and liquids with extremely diverse viscosity, homogenization of melts in polymer processing
SMV	Turbulent	Low viscosity mixing and mass transfer in gas–liquid systems Liquid–liquid extraction Homogeneous dispersion and emulsions
SMXL	Laminar	Heat transfer enhancement for viscous fluids
SMR	Laminar	Polystyrene polymerization and devolatilization
LPD	Laminar	Blend two resins to form a homogeneous mixture
ISG	Laminar	Blending catalyst, dye or additive into viscous fluid Homogenization of polymer dope Pipeline reactor to provide selectivity of product

Table 2.3: Applications of static mixers in the process industries (Thakur et al. ,2003)

Industry	**Application**
Chemical and agricultural chemicals	Reaction enhancement Gas mixing Fertilizer and pesticide preparation Steam injection
Grain processing	Continuous production and conversion of starch Liverstock feed mixing
Food processing	Liquid blending and emulsification Starch slurry cooking Solid ingredient bending
Minerals processing	Mineral recovery by solvent extraction Slurry dilution Oxidation and bleaching Chemical addition and bleaching
Petrochemicals and refining	Gaseous reactant blending Gasoline blending Caustic scrubbing of H_2S and CO_2 Lube oil blending Emission monitoring and control
Pharmaceuticals and cosmetics	Mixing of trace elements Blending of multicomponent drugs Dispersion of oils Sterilization pH control
Polymer, plastics and textiles	Continuous production of polystyrene Mixing of polymer additives Preheating polymers Thermal homogenization Fiber spinning Tubular finishing reactors
Paints, resins and adhesives	Dilution of solids (e.g. TiO_2) Colouring and tinting Adhesive dispensing and heating
Pulp and paper	Pulp bleaching Stock dilution and consistency control pH control
Water and waste water treatment	Addition of coagulating agent Sludge dewatering process pH control

2.2.2.1 Kenics Static Mixers

According to Robbins (2013), Kenics Static Mixers have been installed in worldwide since 1965. The installation have set to the standard for in-line mixing and heat transfer performance. Kenics mixer is one of the technology from Chemineer incorporates advanced technology which is responsible for reliable and uninterrupted performance for the long term. The feedback from the installation of Kenics mixer gives maximum operating efficiency and overall cost savings. (Robbins, 2013)

There are several types of static mixer that are available in the market. The KM Static Mixer is designed with helical mixing element directs the flow of material radially toward the pipe walls and back to the centre. In order to increase mixing efficiency, the additional velocity reversal and flow division is required by combining alternating right- and left-hand elements. The HEV and UltraTab Static Mixers are designed with the element geometry which maximizes the conversion of turbulent energy into efficient mixing. The mixing elements are used to produce complete stream uniformity through controlled vortex structures. This type of mixing elements can be easily reproduced and reliably scaled. From previous usage, it shows that Kenics Static Mixers maximize mixing efficiency without the wasted energy and material blockage typically found in more restrictive motionless mixers.

Kenics Static Mixers provide precise blending and dispersion of all flow able materials, without utilizing moving parts. Mixing is achieved by redirecting the flow patterns already present in empty pipe. Kenics Static Mixers are currently being used in numerous processing applications, in order to reduce overall cost and significantly improve efficiency, speed and control. Kenics Static Mixers can be found in a wide range of markets including chemical, refining, polymer, food, pulp and paper, and water and wastewater treatment. These high efficiency mixers also handle other critical processes, such as heating or cooling, residence time control and temperature uniformity. (Robbins, 2013)

2.2.3 Pressure Drop

A greater pressure drop is needed to maintain the same flow rate when mixer elements are inserted in a pipe. There are some procedures in order to get the value of pressure drop in mixing tube. (Sizing The Admixer Static Mixer and Sanitary Static Blender, 1998)

As given by Sylwia Peryt-Stawiarska (2012), the pressure drop, Δp in a static mixer can be calculated as for an empty tube with help of the Fanning friction factor:

$$\frac{f}{2} = \frac{\Delta p}{4\rho w^2}\frac{D}{L} \quad (2.1)$$

Where;

f = Fanning factor

Δp = Pressure drop

ρ = Density of the fluid

D = Hydraulic diameter

L = Length of the tube

w = Velovity

and for Reynolds number $15 < Re \leq 1000$:

$$\frac{f}{2} = \frac{110}{Re^{0.8}} + 0.4 \quad (2.2)$$

Where;

f = Fanning factor

Re = Reynolds number

2.2.4 Coefficient of variance (COV)

According to Fan (1990), the homogeneous mixture is a mixture that having mixing element uniformly. There are several factors that influence the homogeneous mixture which are mechanisms of mixing, characteristics of materials to be mixed and characteristics of the mixer. To analyze a mixture, samples are taken from the mixture at random which represent of the state of the mixture. The level of acceptable homogeneity of the mixture depends on each application. It can be specified in terms of variation coefficient, COV. Usually a COV value between 0.01 and 0.05 is a reasonable target of completely homogeneous mixing fluid for most applications. The lower value of COV represents better quality of the homogenous mixture. The standard COV value equal to 0 represents a complete distributive mixing, while COV value more than or equal to 1 represents total segregation.

According to R.V. (2004), the COV is defined as the standard deviation of concentration, $\boldsymbol{\sigma}$ over the mean concentration, $\bar{\boldsymbol{x}}$ for a given set of data points.

The standard deviation of concentration is:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \qquad (2.3)$$

Where;

σ = Standard deviation

n = The number of data points

$\bar{x}$ = The mean of the x_i

x_i = Each of the values of the data

An alternative measure of homogeneity is provided by the coefficient of variation:

$$COV = \frac{\sigma}{\bar{x}} \qquad (2.4)$$

Where;

$\mathrm{COV} = \text{Coefficient of variation}$

$\sigma = \text{Standard deviation}$

$\bar{x} = \text{Mean concentration}$

2.3 Computational Fluid Dynamic

In this project, ANSYS software is proposed to do simulations of fluid flow in cylindrical pipeline system. Basically, ANSYS software is one of the new Computational Fluid Dynamic (CFD) software that is usually used today. This software provides many features that can be used to study the fluid dynamics, structural mechanics, electromagnetic and systems and multiphysics. In study of fluid dynamics, this software provides the analysis system by using Fluid Flow (CFX), Fluid Flow (Fluent), Fluid Flow(Polyflow), Fluid Flow-Extrussion (Polyflow), Fluid Flow-BlowMolding (Polyflow) and other advanced analysis system. The ANSYS software is used in scope of works starting from drawing of cylindrical pipeline system and static mixer, modeling of the cylindrical pipeline system, simulation and visualization of fluid flow in the cylindrical pipeline system.

2.3.1 ANSYS Software

CFD is the way on engineering field which is used to analyze the flow field and other physics behaviour that act on a body by using computer to compute in detail information. To conduct this project, ANSYS software is used to simulate of fluid flow model which is combination varies types of physics simulation technologies. Simulation driven product development process can be applied for simulation result which getting from interested application. It will give the idea on operation of product or process, optimization of performance and designing a new product. (AG, 2008)

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