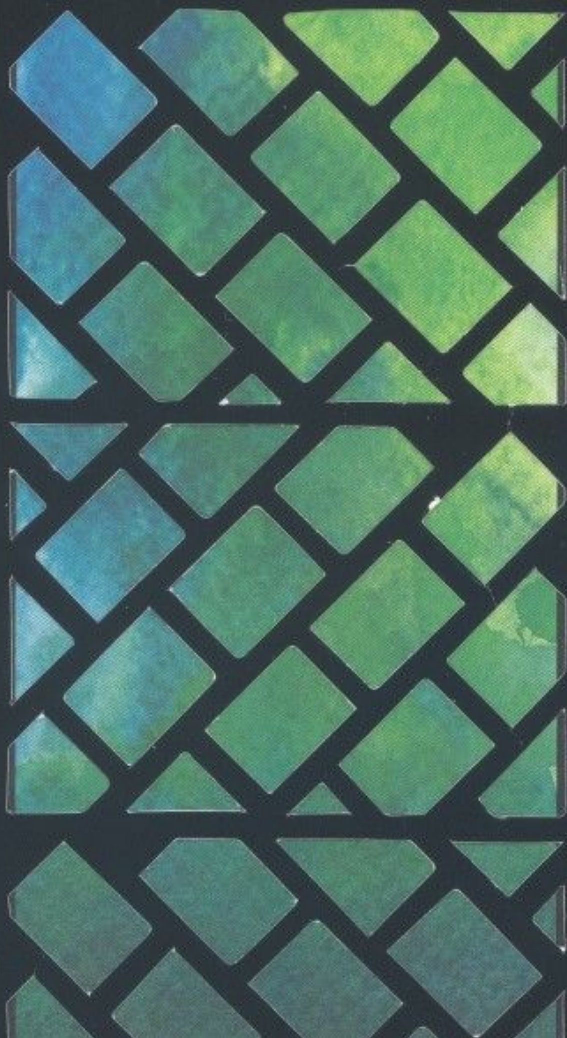
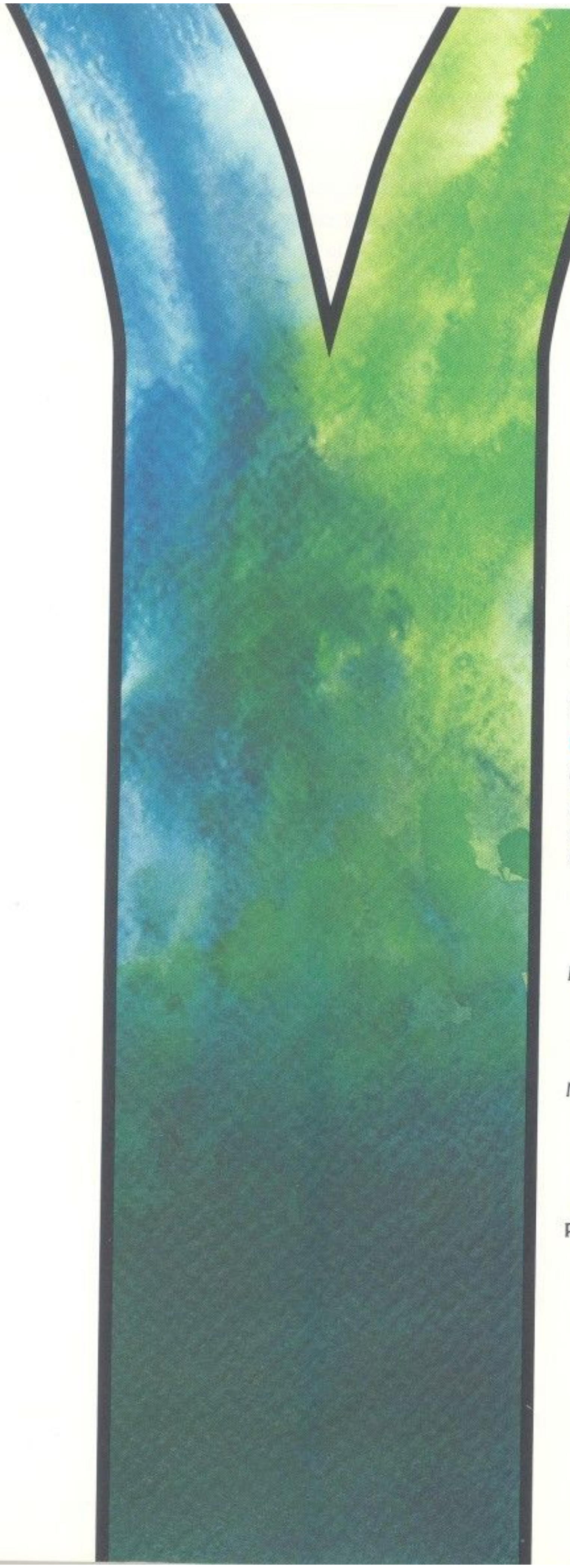
static mixing



KOCH
ENGINEERING COMPANY INC.



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CONTENTS

Motionless Mixing from Koch	1
Operating Principles	2
Specifying a Static Mixing Unit	3
Element Types	3
Homogeneity	4
Pressure drop	4
Size	4
Mixing in Laminar Flow	5
High-viscosity mixing	5
High-low viscosity mixing	6
Plug flow reactors	7
Heat exchangers	8
Mixing in Turbulent Flow	9
Low-viscosity mixing	10
Gas mixing	10
Liquid dispersions	11
Gas-liquid contacting	12
Gas-liquid reactors	12
Put Koch to Work for You	13

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motionless mixing from KOCH

Static Mixing Units Vs. Dynamic Agitator Systems

Characteristic	Static Mixing Unit	Dynamic Agitator
Process	Continuous	Usually batch
Principle of mixing	Geometric	Random
Power requirement	Low	High
Moving parts	None	Many
Maintenance	Negligible	High
Scale-up	Predictable	Unpredictable
Space requirements	Small	Bulky
Investment cost	Inexpensive	Expensive

FIG. 1 Static mixing requires less power, maintenance, and space than dynamic mixing.

FIG.2 Koch makes static mixing elements for a wide variety of applications.

The Koch static mixing unit, an in-line mixer with no moving parts, is a simple, cost-effective solution to your mixing and contacting problems. It consists of a series of stationary, rigid elements placed lengthwise in a pipe. These elements form intersecting channels that split, rearrange, and recombine component streams into smaller and smaller layers until one homogeneous stream exists.

Compare our static mixing unit with conventional dynamic agitators and you'll see that motionless mixing is the right choice for continuous processes. The static mixing unit uses much less power, and since it has no moving parts and no electrical hook-up, the static mixing unit requires no maintenance. And its precise geometric construction means it's easy to scale-up to industrial size units.

What's more, the static mixing unit is compact and easy to install. More affordable than dynamic agitator systems, the Koch static mixing unit has a long life and a low pressure drop. Units can be fabricated from most plastics and metals....to fit pipes or vessels of any size and shape....for a wide range of industrial applications.

operating principles

Any stationary baffle installed in a pipe will utilize the energy of the flowing fluid to produce mixing. The baffle represents a crude motionless mixer—one that gives unpredictable mixing efficiency as equipment size and flow conditions change. What is worse, appreciable mixing occurs only under turbulent flow conditions.

The Koch static mixing unit, on the other hand, provides precise geometric paths for fluid flow. This results in consistent, predictable mixing performance, regardless of flow rate or equipment dimensions.

Koch static mixing elements are made from intersecting bars or corrugated sheets welded together to form open channels. These elements, when placed end to end along the length of a section of pipe, form the static mixing unit: a series of open, intersecting channels for fluid flow.

The fluids to be mixed enter the unit and are split into individual streams in the channels. These channels provide strong transversal flow and fluid exchange at the pipe wall. At each channel intersection, a part of the fluid shears off into the crossing channel.

Adjacent mixing elements are positioned 90° relative to each other, so two-dimensional mixing takes place over the first element and three-dimensional mixing over all successive elements. This three-dimensional mixing ensures uniformity in composition, concentration, viscosity, and temperature.

Depending on the type of process and the desired characteristics of the final product, any number of elements may be added in series to form the static mixing unit. The highly adaptable Koch mixer easily fits into existing process pipelines or can be added to a system with minimal piping modification.

FIG.3 A Koch static mixing unit consists of a series of stationary rigid elements placed lengthwise in a section of pipe.

specifying a static mixing unit to meet your requirements

Design of the static mixing unit is usually based on three customer-specified parameters:

1. *Homogeneity* or quality of the final mix.
2. Maximum allowable *pressure drop* across the mixer.
3. *Size* limitations (length and diameter).

Given these parameters, Koch can design a static mixing unit using one of three different element types. SMV elements are chiefly used for turbulent flow, SMX for laminar, and SMXL for either laminar or turbulent.

Each type of element has its own special advantages in different applications. But whatever your application, a Koch static mixing unit can provide complete mixing in the shortest possible mixer length....with a comparatively low pressure drop.

KOCH Makes Static Mixing Elements For Every Application

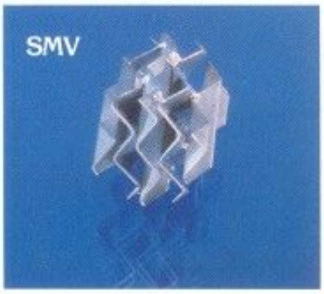
Mixing Elements	Operational Environment	Construction	Applications
SMV 	Primarily turbulent flow (with some laminar applications)	Corrugated plates stacked together to form open intersecting channels at 45° to the pipe axis	Mixing low-viscosity liquids; mixing gases; liquid dispersion; gas-liquid contacting; homogenizing melts in plastic processing
SMX 	Laminar flow	Intersecting bars at 45° to pipe axis	Mixing high-viscosity liquids and liquids with extremely diverse viscosities; inducing plug flow; boosting heat transfer; homogenizing melts in plastic processing
SMXL 	Laminar flow/turbulent flow	Intersecting bars at 30° to pipe axis; space between the bars is larger than in SMX elements	Viscous heat exchange; mixing high-viscosity liquids at negligible pressure drops; mixing slurries

FIG.4 In each Koch static mixing element, the open intersecting channels are either 30° or 45° relative to the pipe axis. Individual applications will determine the channel angle, the number of plates or bars used to make the element, and the material of construction. Common materials of construction include carbon steel, stainless steel, polypropylene, and PVC. Teflon, Kynar, FRP, and other, more exotic materials are also available.

HOMOGENEITY

The degree of homogeneity achieved is a measure of how completely mixing has occurred: A perfectly homogeneous mixture is totally uniform in composition. Homogeneity is a function of both element geometry and the length of the unit (the number of elements in the mixer). The statistical measure of homogeneity may be expressed as a variation coefficient $\sigma/\bar{x}$, where σ is the standard deviation from the arithmetic mean $\bar{x}$, and

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

and x_i is temperature, concentration, electrical conductivity, or some other measurable variable.

The lower the value of $\sigma/\bar{x}$, the more homogeneous the mixture. For most industrial applications, the homogeneity of the final mix $\sigma/\bar{x}$ need not be smaller than 0.05; that is, five percent standard deviation from the arithmetic mean.

As the channels of a motionless mixer split and rearrange fluid streams, more and more fluid layers are formed as the fluids become mixed. Early in the development of motionless mixing technology, layer formation theories were developed that described homogeneity in terms of the number of fluid layers formed. Exponential equations derived from these theories predicted that static mixing units could produce more than a billion fluid layers.

Since less than a hundred layers can be verified optically (or by any other method), layer generation theories have remained theories—it's simply not possible to measure homogeneity by counting layers.

Only through the precise, measurable variation coefficient ($\sigma/\bar{x}$) can homogeneity be predicted quantitatively and not just qualitatively.

PRESSURE DROP & POWER REQUIREMENTS

Unlike dynamic agitators, which require electricity to drive their moving parts, static mixing units don't need to be plugged into an external power source. But it does take some energy to overcome the fluid flow pressure drop (Δp) across the mixing unit. This extra power—typically one-tenth the power requirement of a dynamic agitator—is easily provided by the process system's pump, fan, or extruder. By combining element types and diameters, we can design a static mixing unit for virtually any pressure drop limitation.

For laminar flow the pressure drop (Δp_l) is given by

$$\Delta p_l = 8.9 \times 10^{-8} (NeRe_D) \frac{\mu \dot{M}}{\rho D^3} (L/D)$$

The Newton number-Reynolds number product ($NeRe_D$), is a convenient parameter for categorizing element geometry with friction factor in laminar flow. An $NeRe_D$ value of 1200 is used for SMX elements and an $NeRe_D$ of 250 for SMXL elements.

In turbulent flow the pressure drop (Δp_t) is

$$\Delta p_t = 3.6 \times 10^{-5} Ne\ (\rho Q^2/D^4)\ (L/D)$$

where $Ne \approx 1.9$ for SMV elements.

To calculate the power needed to drive the static mixing system ($\dot{L}$), multiply the pressure drop by the volumetric flow rate,

$$\dot{L} = 5.8 \times 10^{-4} \Delta p Q$$

SIZE

Because mixing takes place as fluids flow along the length of the static mixing unit, homogeneity is a function of mixer length (usually expressed as a relative length L/D, where L is the length of the unit from entrance to exit and D its diameter). For most applications, the Koch static mixing unit will achieve the desired degree of homogeneity in a shorter length than other in-line mixers can. A shorter mixing unit means lower capital costs and a shorter residence time.

FIG.5 Typical retainer assembly (above) for a Koch static mixing unit.

FIG.6 The degree of homogeneity increases (the variation coefficient $\sigma/\bar{x}$ decreases) as fluids flow up the length of the mixing unit (right).

mixing in laminar flow

Laminar flow generally occurs when fluid viscosities are over 100 cp. SMX elements are most often used here, with SMV or SMXL the choice in certain special applications. The major laminar flow mixing situations include high-viscosity mixing, high-low viscosity mixing, plug flow reactors, and viscous heat exchangers.

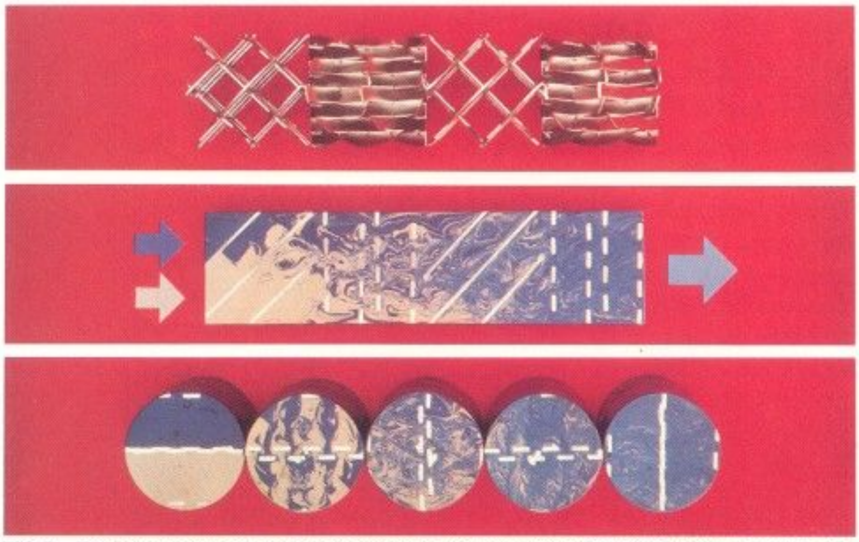


FIG.7 Two epoxy streams are split, sheared, and recombined in the intricate channels of a static mixing unit until one homogeneous stream exists.

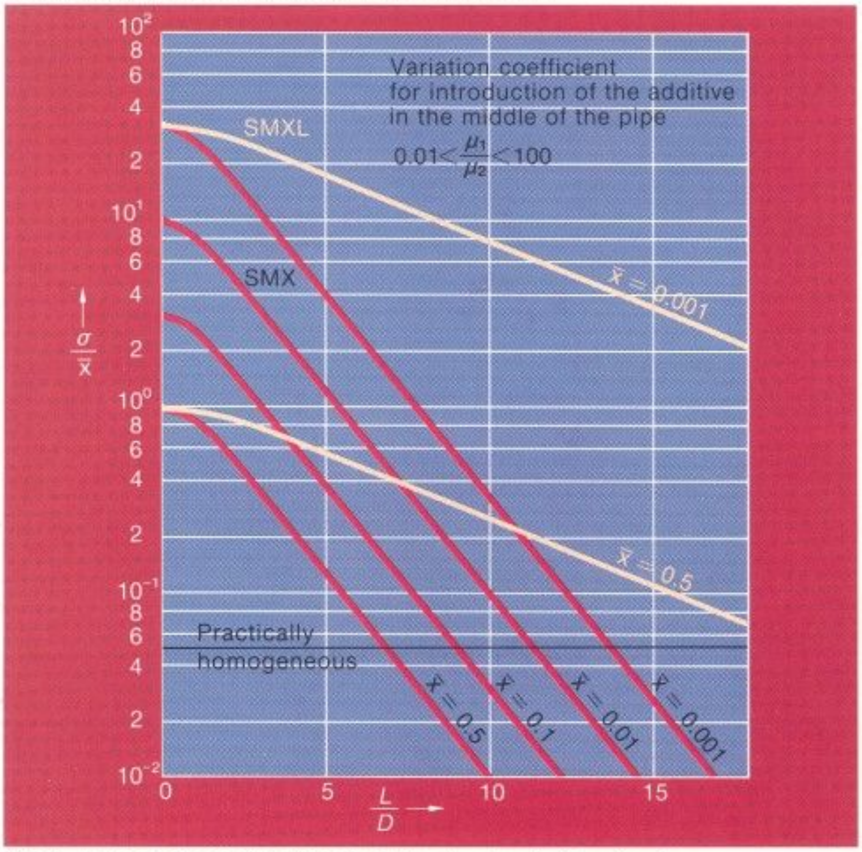


FIG.8 Homogeneity as a function of relative mixer length in laminar flow.

HIGH VISCOSITY MIXING

The unique design of the Koch SMX static mixing unit makes it particularly well suited for what is certainly the toughest of mixing problems: mixing fluids where one or more of the components is highly viscous.

Figure 7 (left) shows how the elements of the Koch mixer repeatedly divide and recombine two fluids over the entire pipe cross section. The degree of homogeneity increases exponentially with increasing mixer length. (To make the photograph, the two viscous resins were pumped through the Koch static mixing elements and allowed to harden. Then, the whole assembly—mixer and hardened epoxies—was cut longitudinally and radially at the intersections of the elements.)

Some high-viscosity mixing applications include:

- Mixing pigments into resins or polymer melts
- Thermal homogenization of polymers in melt lines, e.g. before branching in spinning manifolds
- Mixing epoxy resins with hardeners
- Mixing TiO_2 pastes into polymer melts for delustering
- Homogenizing photographic emulsions
- Improving melt homogeneity on pipe extrusion operations

HIGH-LOW VISCOSITY MIXING

Mixing fluids with viscosity ratios of over one thousand to one is the most difficult mixing job of all. But even when the viscosity ratio is as high as *ten million* to one, the Koch static mixing unit achieves a homogeneous mix. The flow regime for these tasks is generally laminar; thus, type SMX elements are used.

As you can see in Figure 11, the red, low-viscosity additive is split into layers. These layers even out as the fluids progress through the mixer, until the viscosity of the mix is completely uniform.

In Figure 9 (below), approximate values are given for the mixer length needed to mix two fluids with high viscosity ratios. Lengths are about 50 percent greater than for mixers where the fluids are of similar viscosities.

$Q_1:Q_2$	L/D for $\sigma/\bar{x} = 0.05$	
	$\mu_2:\mu_1 = 1000$	$\mu_2:\mu_1 = 100000$
0.001	17	20
0.01	15	18
0.1	12	15
1	11	13
10	7	8
100	5	5
1000	5	5

FIG.9 Mixer length as a function of volumetric flow rates ($Q_1:Q_2$) for two different viscosity ratios ($\mu_2:\mu_1$).

FIG.10 The Koch SMX static mixing unit is generally recommended for laminar flow where its performance is unmatched by any other motionless mixer.

High-low viscosity applications include:

- Mixing mineral oil or other low-viscosity additives into polymers, e.g. polyethylene or polystyrene
- Mixing foaming agents into urethane resins
- Mixing enzyme solutions with starch hydrolyzate
- Mixing a dyestuff solution into nylon or rayon
- Diluting molasses with water
- Diluting flocculants with water, e.g. polyacrylamide

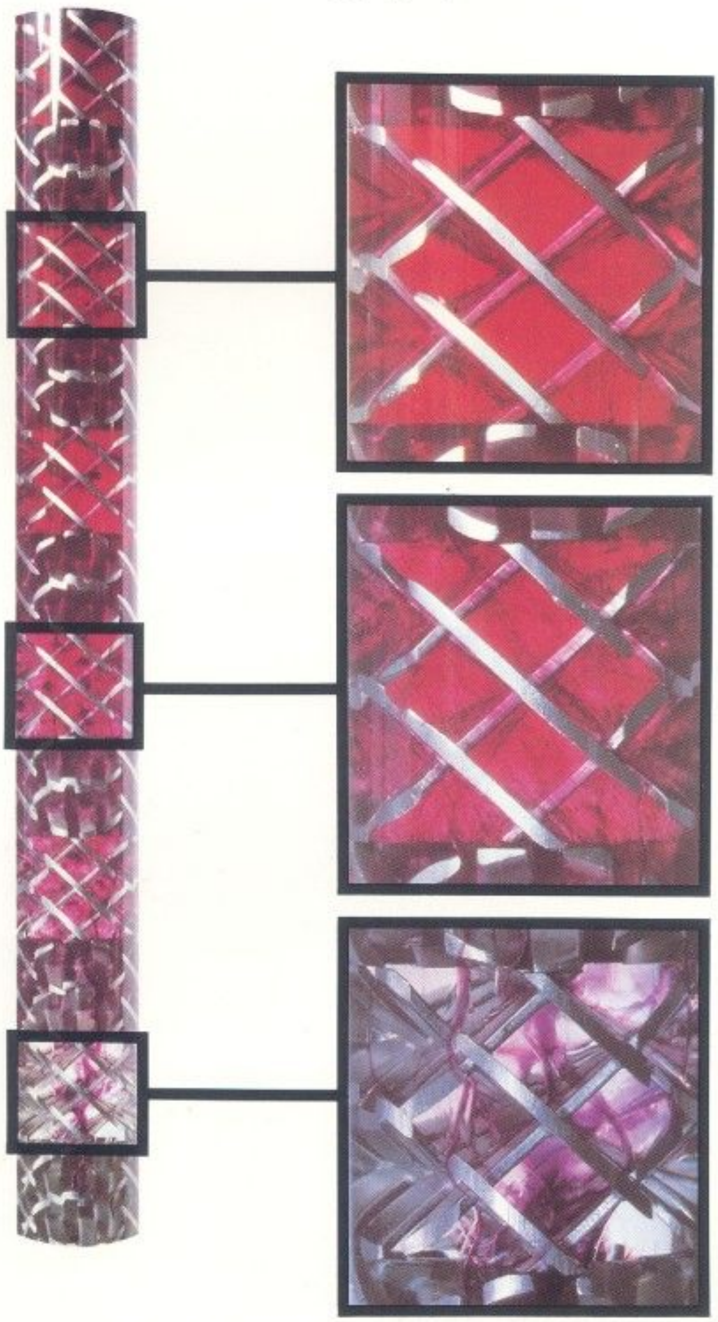


FIG. 11 Mixing water (dyed red) with glucose is accomplished in a relatively short mixer length.

PLUG FLOW REACTORS

Static mixing units provide the radial mixing and plug flow needed to perform continuous chemical reactions.

Radial mixing. In laminar flow ($Re_D \leq 2{,}100$), fluids will pass through an empty pipe in the axial direction, with virtually no radial mixing. Only in fully developed turbulent flow ($Re_D \geq 10{,}000$) will some radial mixing occur.

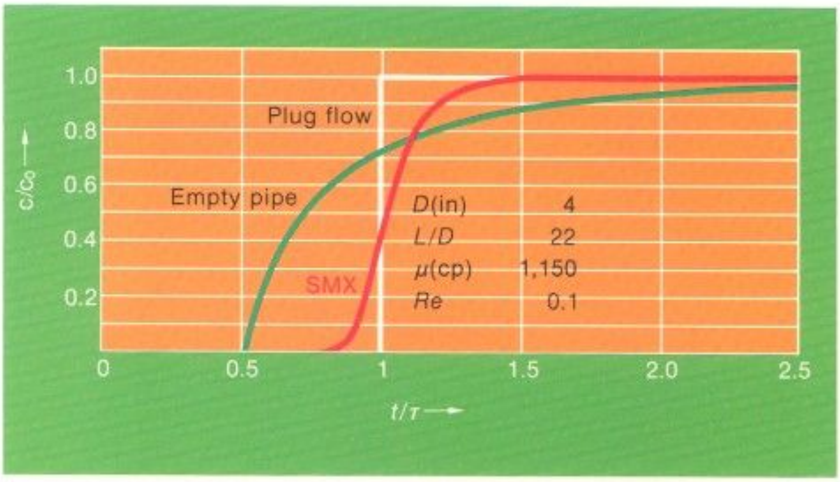


FIG.12 Koch static mixing units induce plug flow in pipes.

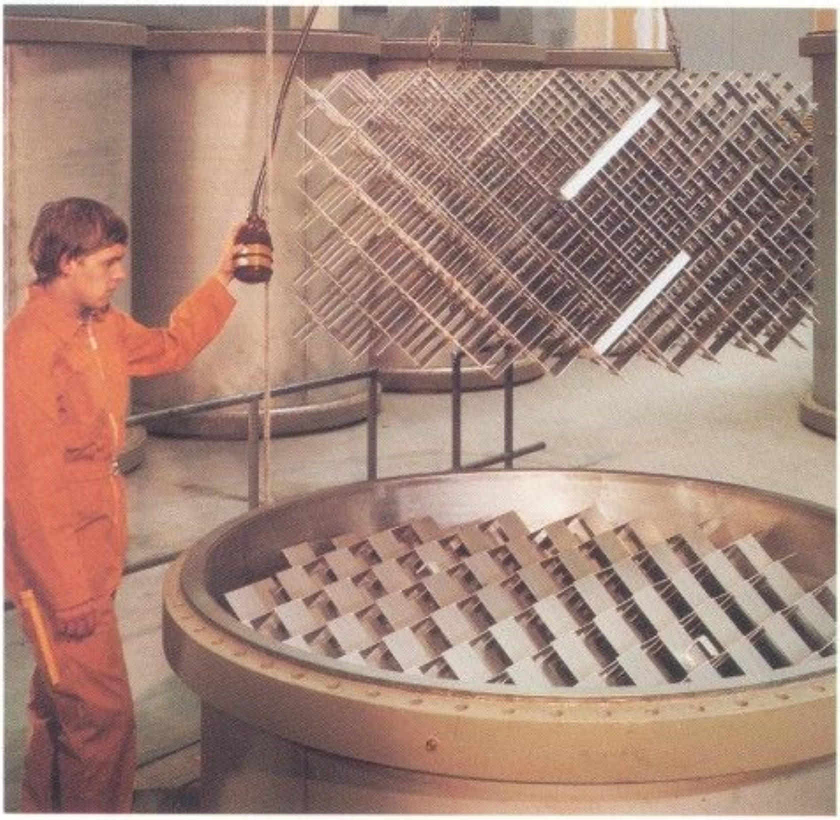


FIG.13 Polymerization reactor with SMX mixing elements.

This means that viscous material flowing in the center of the pipe will tend to exit unmixed in the same position. But by forcing this material to follow intersecting flow channels, the Koch static mixing unit creates radial flow—even in the laminar flow regime.

Plug flow. Ideally, continuous reactors require perfect plug flow. This means that all the product passes through the reactor within a defined time interval. An empty pipe makes a poor continuous reactor because the material in the center of the pipe travels at nearly twice the average product velocity, while the material at the wall travels much slower. The result? Material in the center exits so quickly that it's not fully reacted, while the slow-moving product near the wall spends too much time in the reactor. This wall drag can cause product buildup on the reactor wall and possible product degradation.

By inducing radial mixing, the Koch static mixing unit provides plug flow and uniformity in viscosity, molecular weight, temperature, and degree of reaction. This eliminates product buildup while raising throughput and yield.

Applications of the Koch mixer as a plug flow reactor include:

- Polymerization of silicones, polystyrene, and nylon
- Chemical reactions in laminar flow requiring a narrow residence time distribution

HEAT EXCHANGERS

In an empty pipe, the thermal boundary layer that builds up along the pipe wall inhibits heat transfer. The Koch SMXL static mixing unit induces a strong transversal flow that virtually eliminates this boundary layer, raising the heat transfer coefficient. And by inducing radial flow, the SMXL unit maintains a uniform temperature over a given cross section of pipe. This prevents "hot spots" caused by exothermic reactions and insufficient cooling at the center of the pipe.

The Koch viscous heat exchanger achieves efficient heat transfer with a minimal surface area. So it takes less space, reduces residence time, and offers significant savings in construction costs for units fabricated from exotic materials.

Some applications of this unique viscous heat exchanger include:

- Food—pasteurizing temperature-sensitive foodstuffs
- Plastics—heating and cooling polymer melts, e.g. cellulose acetate, polystyrene, PVC
- Adhesives—heating and cooling at various process stages in adhesives production
- Chemical—removing heat from exothermic reactions in laminar flow

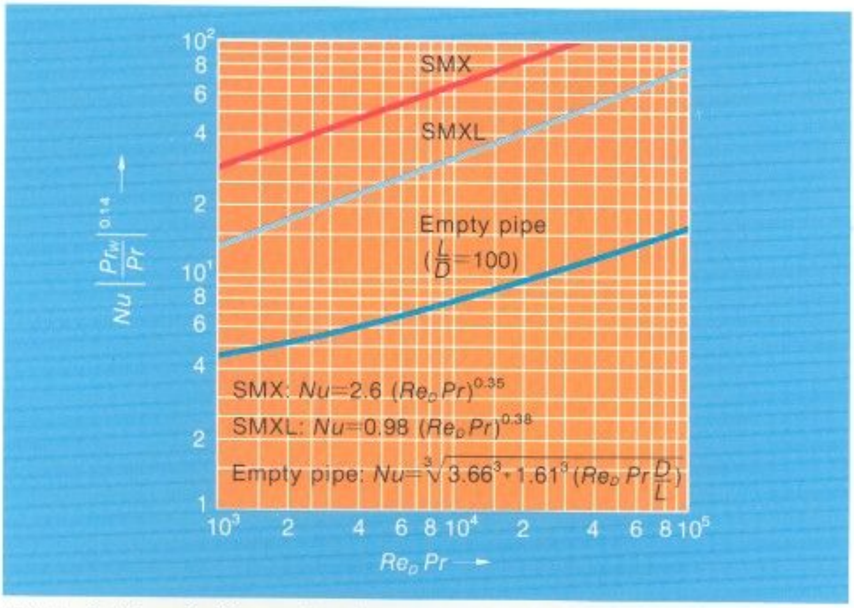


FIG.14 Heat transfer is boosted by a factor of three to six when Koch SMX or SMXL elements are placed in an empty pipe.

FIG.15 The Koch multitube viscous heat exchanger is used for large volumetric flow rates where space and residence time must be kept to a minimum.

FIG.16 The Koch monotube heat exchanger is the simple, low-cost solution to viscous heating or cooling problems.

mixing in turbulent flow

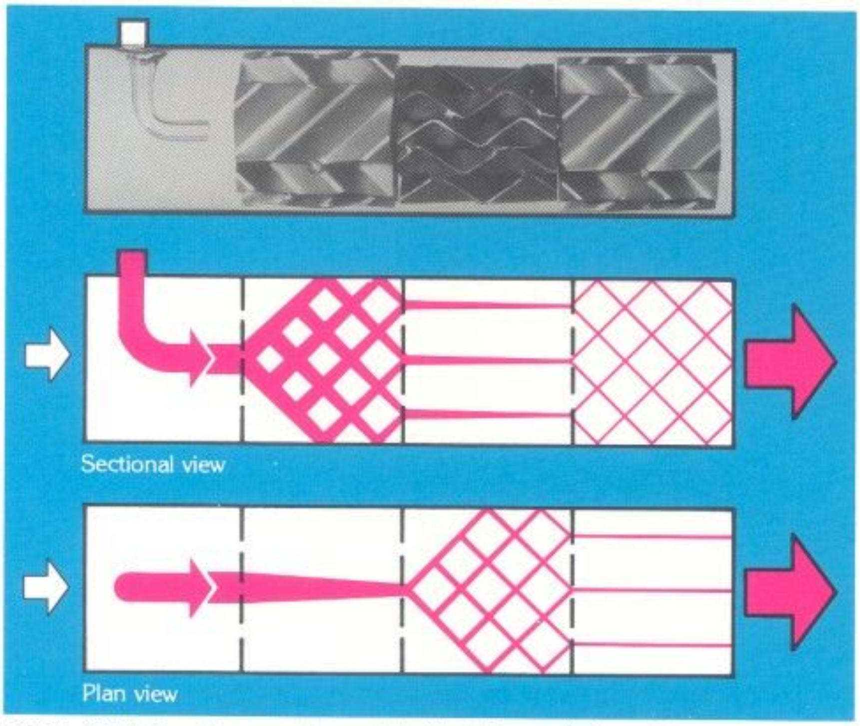


FIG.17 SMV elements are used in most turbulent flow applications. Note that adjacent elements are positioned 90° relative to each other to ensure three-dimensional mixing.

Turbulent flow occurs with low-viscosity fluids ($\leq$100 cp) like aqueous solutions, organic solvents, and gases. But even turbulent flow doesn't assure thorough mixing will take place in a short length of empty pipe; the mixing of compatible liquids or gases may require 100 pipe diameters or more.

With the Koch static mixing unit, a homogeneous mix is achieved in just a few pipe diameters. SMV elements are used in most turbulent mixing applications, SMXL elements in a few special cases. Major turbulent flow mixing tasks include mixing low-viscosity liquids, mixing gases, liquid dispersions, gas-liquid contacting, and gas-liquid reactors.

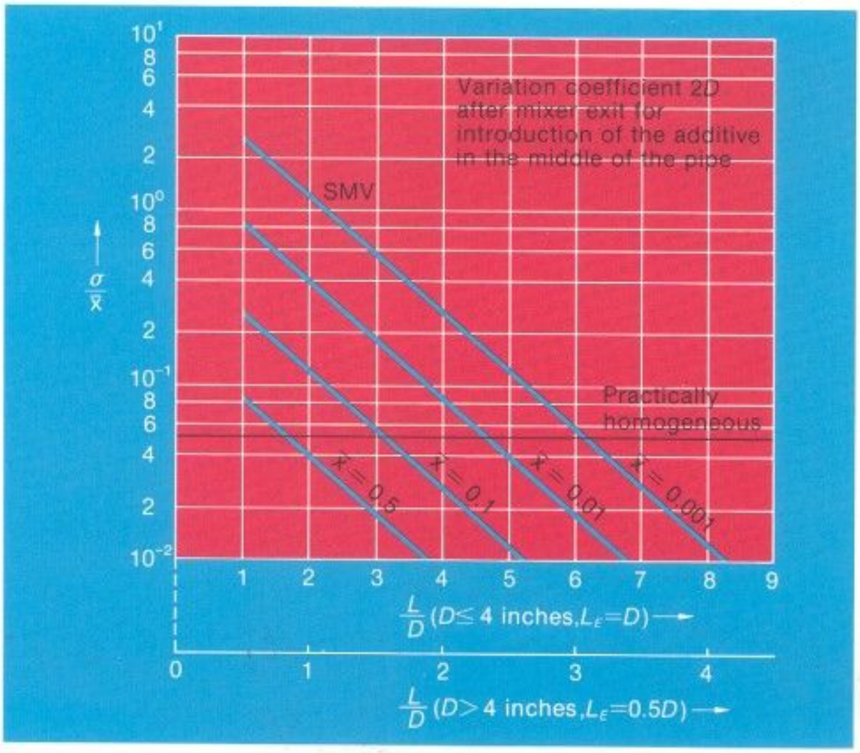


FIG.18 Homogeneity as a function of relative mixer length in turbulent flow.

FIG.19 In this acid-lye decolorization test, the base (dyed red) is completely neutralized after passing through three SMV elements.

MIXING LOW-VISCOSITY LIQUIDS

Figure 19 shows the mixing of two low-viscosity fluids. Here a neutralizing base (dyed red with phenolphthalein indicator) is introduced into the center of a pipe processing an acidic solution. After passing through only three SMV elements, a colorless, neutralized (and therefore homogeneous) mixture is obtained.

Other low-viscosity mixing tasks include:

- Diluting concentrated acids or bases with water
- In-line neutralization or pH adjustment of product streams in the chemical and water treatment industries
- Blending refinery and petrochemical products
- Admixing flocculants in water treatment
- Mixing additives or inhibitors into chemical product streams

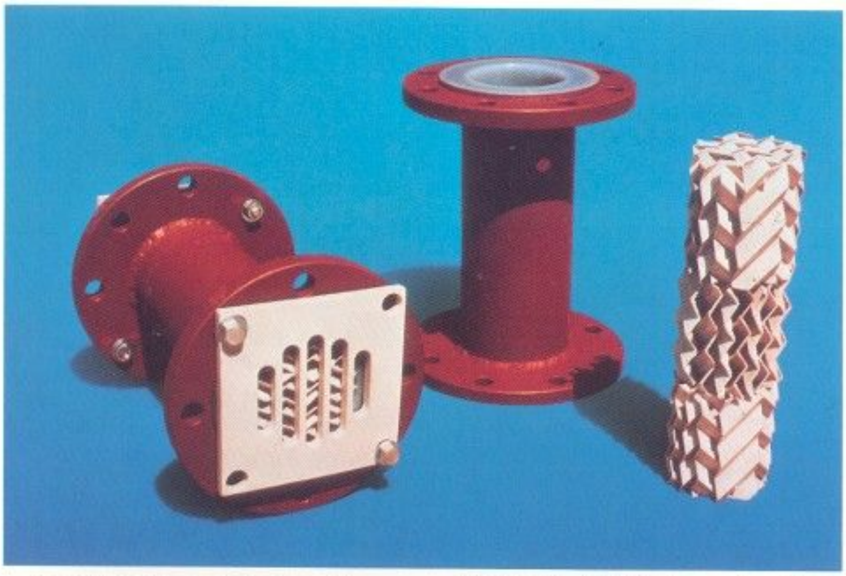


FIG.20 Koch SMV mixer made of Teflon.

GAS MIXING

The turbulence of flowing gases is not enough to eliminate inhomogeneities in concentration and temperature over short lengths of empty pipe. Even at high velocities, gases with significant differences in density can stratify and form relatively stable stream layers, and it can take up to several hundred pipe diameters to achieve a homogeneous mixture.

With a Koch SMV static mixing unit fabricated to fit a pipe or duct of any size and shape, the gases mix in just a few pipe diameters. This results in a big cost savings when you're working with large gas ducts. And the pressure drop is low—only a few times the velocity head.

There are numerous applications of the Koch static mixing unit in gas-gas mixing:

- Mixing warm and cold air, e.g. air conditioning before fluid bed dryers
- Adjusting Btu content in natural gas by admixing butane or propane
- Mixing gases in iron ore direct reduction plants
- Injecting hot gases into cooled scrubbed gases to avoid stack condensation
- Mixing hot flue gases with ambient air for cooling and temperature homogenizing prior to processing through an electrostatic precipitator, e.g. incinerator plants and power stations
- Blending fuel gases with air before combustion
- For representative sampling in measuring and control engineering
- Eliminating concentration gradients in feed gases for catalytic reactors, e.g. air/NH_3 mixing in nitric acid plants

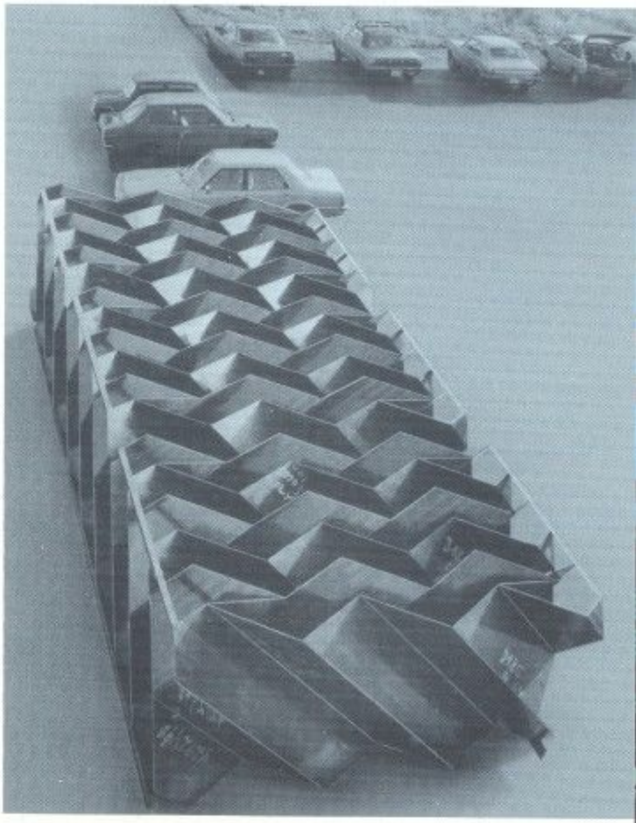


FIG.21 Gas mixer with a cross section of 13 feet by 26 feet.

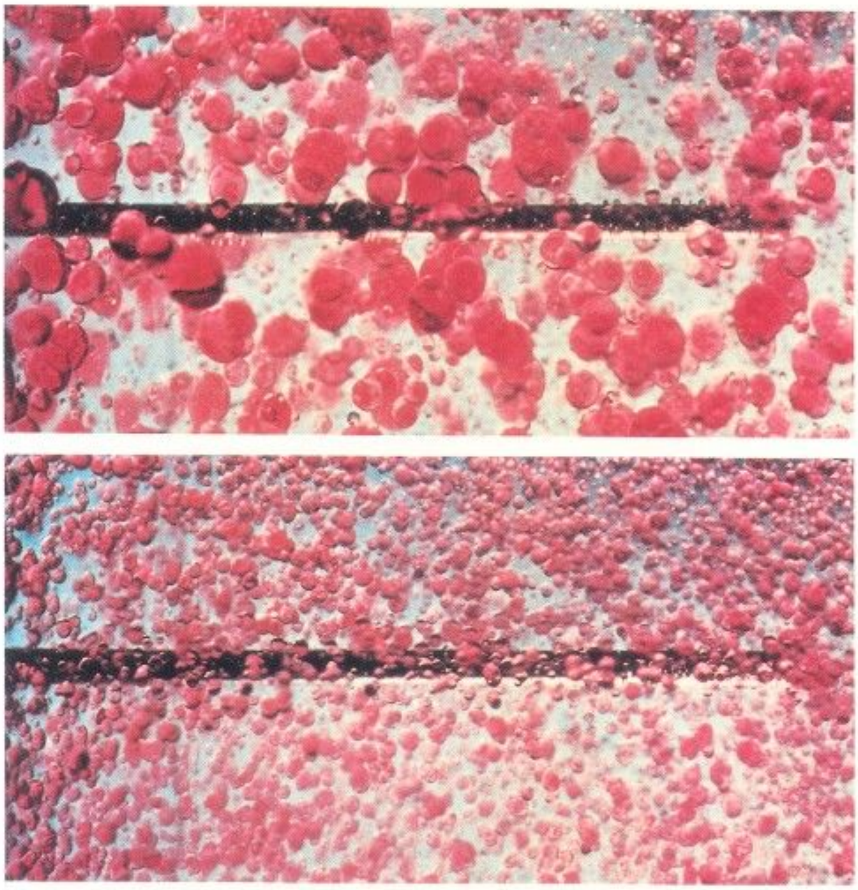


FIG.22 Drop patterns of liquid-liquid dispersions generated by five SMV mixing elements. The dispersed phase is kerosene, the continous phase water; phase ratio is 0.03. The reference needle is 1,500 microns in diameter. Velocities are 0.49 ft/s (top photo) and 1.64 ft/s.

LIQUID DISPERSIONS

Continuous contacting of two immiscible fluids results in distinct phases known as *dispersions*. Mixing valves, orifice plates, dynamic in-line agitators, pumps, and other devices used to create dispersions generally yield an undesirably wide drop size distribution and are not energy efficient.

But the Koch SMV static mixing unit, with its unique geometrical configuration, creates a controlled droplet size with a narrow drop size distribution. As fluids flow through the tortuous mixer channels, continuous renewal of the dispersed phase surface area takes place, accelerating mass transfer. The motionless mixing unit accomplishes this using far less power than other dispersion-generating equipment. The relationship between drop size and pressure drop is presented in Figure 23.

Correlation between drop size and pressure drop for water as continuous phase.

	Flow velocity (ft/s)								
	0.82			3.28			8.20		
Hydraulic diameter D_h (in) of SMV mixing elements	0.16	0.32	0.64	0.16	0.32	0.64	0.16	0.32	0.64
Mean drop diameter d_s (microns) for σ' =35 dynes/cm	900	1100	1800	300	350	500	100	150	250
Pressure drop per foot disperser length (psi/ft)	0.26	0.22	0.09	4.0	3.32	1.33	24.7	20.0	7.9

FIG.23 Drop size increases as pressure drop decreases.

Applications of the Koch mixer in in-line liquid dispersion include:

- Mercaptan removal from hydrocarbon streams
- Desalination of crude oil
- Washing impurities out of organic substances with water
- Alkylation, sulfonation, and saponification processing in petrochemical plants
- Creating stable oil-water emulsions prior to combustion for increased boiler efficiency
- Regenerating lubricating oil with sulfuric acid
- Neutralizing hydrocarbons (sweetening)
- Sampling crude oil for water content
- Countercurrent extraction with mixer/setter design

GAS-LIQUID CONTACTING

In addition to liquid dispersion, Koch static mixing units are used to disperse gases into liquids for a variety of chemical process and water treatment applications. The static mixing elements continuously renew the gaseous bubble surface area, enhancing mass transfer between phases. This is accomplished by subjecting gas bubbles to shearing forces within the mixing elements.

Applications include:

- Aeration, iron removal, or deacidification of drinking water with ozone, oxygen, chlorine, or fluorine
- Chlorination of organic materials
- Production of sodium hypochlorite bleach liquor by dissolving chlorine gas into sodium hydroxide solution
- Dissolution of ammonia into aqueous solutions
- Neutralization of wastewater with CO_2
- In-line oxidation of effluents containing sulfite
- Cocurrent gas scrubbing

FIG.24 SMV elements generate a bubble bed in air-water contacting.

GAS-LIQUID REACTORS

In the Koch gas-liquid reactor, incoming gas is distributed underneath an inner tower filled with Koch SMV static mixing elements. The gas rises through this static mixing "packing" and aerates the liquid. Density differences between the aerated liquid in the inner tower and nonaerated liquid in the annulus result in a high recirculation rate inside the tower.

Static mixing packing breaks the gas into fine bubbles and disperses it uniformly throughout the liquid. Fine gas bubbles and a high liquid flow rate result in increased mass transfer efficiency. The Koch gas-liquid reactor provides excellent gas-liquid contact in a small volume, with no moving parts, and at a considerably greater efficiency than conventional equipment.

Figure 26 shows a Koch reactor for the oxidation of sodium sulfite solution from scrubber blowdown. A pilot plant is available for customer tests. Other applications include:

- Oxidation of sodium, ammonium, and potassium sulfite solutions
- Oxidation of organic products
- Fermentation

FIG.25 In the Koch gas-liquid reactor, static mixing packing breaks the gas into fine bubbles and disperses them uniformly throughout the liquid.

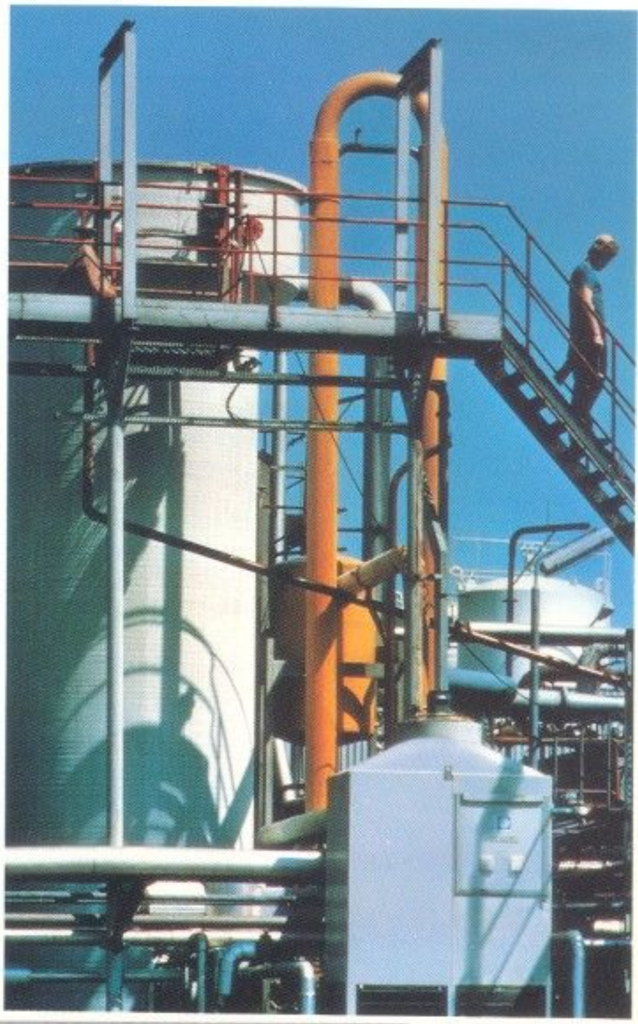


FIG.26 Koch reactor for the oxidation of Na_2SO_3 to Na_2SO_4.

put KOCH static mixing to work for you

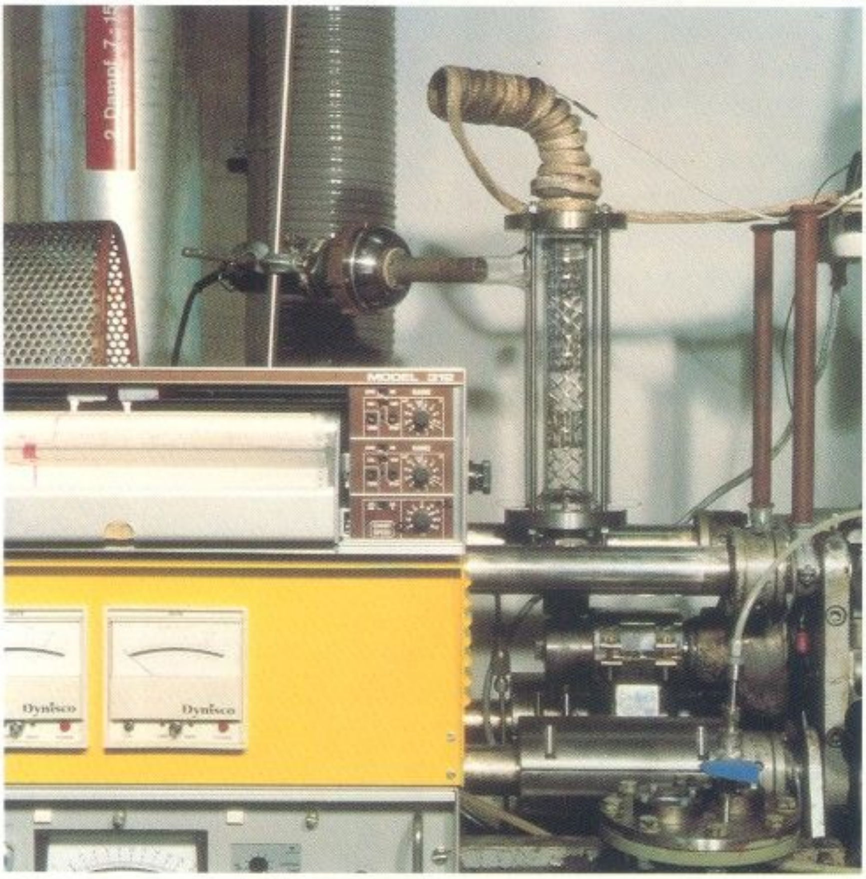


FIG.27 Static mixing test facility for high-low viscosity mixing applications.

The Koch Engineering Company designs, manufactures, and markets equipment for refineries, chemical plants, and related industries. In addition to static mixing units we make trays, tower packings and internals, mist eliminators, and air pollution control equipment.

Founded in 1925, Koch Engineering is a wholly owned subsidiary of Koch Industries, Inc., one of the largest privately owned firms in the United States. Koch Industries, whose annual sales are in the billions of dollars, is primarily an integrated energy company. Both Koch Industries and Koch Engineering have their headquarters in Wichita, Kansas.

Now that you've seen what our static mixing unit can do, why not put it—and us—to work for you? Koch offers complete engineering capabilities including pilot plant facilities for the evaluation of your mixing requirements.

If you have a mixing problem, please complete and mail the attached "Koch Static Mixing Specification Sheet." If you don't have the sheet, or need immediate service, give us a call.

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Notation

c/c_o	Relative concentration	(−)
C_p	Specific heat	(Btu/lb·°F)
D	Inside pipe diameter	(in)
D_h	Hydraulic diameter of mixer	(in)
d_S	Mean drop diameter according to Sauter	(microns)
L	Mixer length	(in)
L_e	Length of mixing element	(in)
$\dot{L}$	Power requirement	(hp)
$\dot{M}$	Mass throughput	(lb/h)
n	Number of samples	(−)
Δp	Pressure drop	(psi)
T	Temperature	(°F)
ΔT	Temperature difference	(°F)
t	Time	(s)
Q	Volumetric flow	(gpm)
x_i	Locally measured variable	
$\bar{x}$	Arithmetic mean	(−)
Ne	Newton number	(−)
Nu	Nusselt number	(−)
Pr	Prandtl number	(−)
Re_D	Reynolds number related to inside pipe diameter	(−)
Re	Reynolds number related to the hydraulic diameter of the mixer	(−)
We	Weber number	(−)
μ	Absolute viscosity	(cp)
ρ	Density	(lb/ft^3)
σ	Standard deviation	(−)
σ'	Interfacial tension	(dynes/cm)
τ	Mean residence time	(s)

Indices

o	Mixer entry
l	Laminar
t	Turbulent