AmAr®

TRUST 50 YEARS INNOVATIONS

AmAr™ FLOW LABORATORY

MEGA LAB

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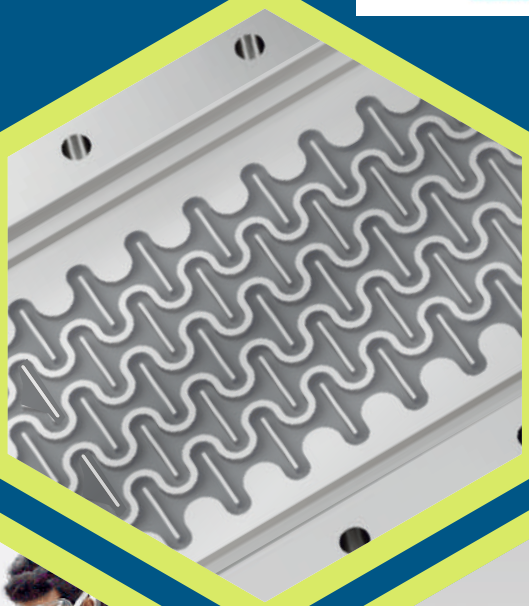


FLOW TECHNOLOGY

About AMAR

Serving Industry Since 1974

50000 sqft state-of-the-art manufacturing facility

Largest manufacturer of pressure & flow reactors in India

Expertise in custom designing high pressure & flow systems

Well equipped flow chemistry process developed lab

Exports to over 50 countries worldwide

Over 7500 successful installations worldwide

More than 2500 delighted customers globally

Manufacturing on CNC, VMC & automated machines

Unmatched quality & safety standards

ISO, CE-PED, ASME U, CSA, UL, Ex-Proof, ATEX certification

Prompt & efficient after sales service

Highly skilled & trained team of more than 200 personnel

OUR PRODUCTS

Pressure Reactor & Systems

Stirred Pressure Autoclaves
Plant Scale Pressure Reactors
Parallel Synthesizer
React-7
Magnetic Couplings & Stirrers
Pressure Vessels
Acid Digestion Bomb
Shaker Hydrogenator
Super Critical Fluid Extraction
HPHT Corrosion Testing
Gas Hydrate Formation System

Agitated Nutsche Filter & Dryer

Custom-built Skids

Flow Reactor & Systems **Pg. no.**

AmarFLO™ Reactors

SALIENT FEATURES

- Available in integrated microchannel & tubular metal construction for continuous flow process
- Reactors from 1mL to 1,000L with throughput up to 10 ton/hr
- 3D printed metal microreactors
- Very high heat and mass transfer coefficient
- Pressures up to 350 bar & temperatures up to 500°C
- SS316, Hastelloy, Inconel, Titanium, etc. materials
- Suitable for various liquid-liquid, gas-liquid - multiphase reactions, and reactions involving solids
- Lab to plant scale turnkey solutions with pumps, utilities, pressure & flow control, safety device with automation & SCADA software

APPLICATIONS

AmarFLO™ Reactor series is ideal for carrying out a wide range of chemical reactions in the field of pharmaceuticals, fine and specialty

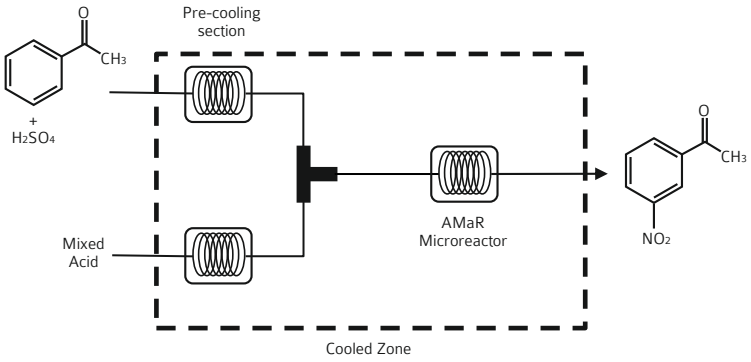
Suitable solutions for

- Homogeneous reactions: Neutralization, condensation, dehydration etc.
- Multiphase Reactions:

  - Gas-liquid reactions (G-L): oxidation, ozonolysis, halogenation, chlorination, bromination etc.

  - Liquid-liquid reactions (L-L): nitration, diazotization, azo coupling, transfer hydrogenation, sulfoxidation, amination, nitration of aromatic substrate, acylation, formylation, methylation, synthesis of nanomaterials, knoevenagel condensation, meerwein arylation, glycosylation hydrolysis, alkylation, sulfonation, sulfoxidation, synthesis of deuterated solvents, acetylation, oximation, cyclization etc.

  - G-L-S and L-S catalytic reactions: hydrogenation, pyrolysis, gasification, vapour phase reactions, etc.



GUIDELINES ON WHEN TO USE AmarFLO REACTORS

- **Inconsistent batch performance** due to high sensitivity towards process variables (temperature, pressure, concentration, time and mixing)

- **Process needs**
  - High heat transfer area
  - Efficient mixing
  - Rapid mass transfer
  - High interfacial area

- **Safety issues in**
  - Storing large inventories of hazardous reactants
  - Handling of hazardous and unstable chemicals
  - Generation of unstable intermediate by-products during the reaction
  - Runaway reactions

- **Process waste related issues**
  - Need for enhancing the selectivity close to theoretical value
  - Avoiding generation of waste that would need treatment
  - Need to avoid or reduce the downstream processing efforts for purification

- **Distributed production**
  - Produce only as per the local requirement/ consumption (location wise production)
  - Produce only as and when needed (avoid inventories)

- **Optimal utilization of facility**
  - A continuous flow manufacturing facility can also be used for production of multiple products with almost same peripherals
  - Space occupancy will be less
  - Achieve same or even better results than conventional

Special Report

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Making profits flow: Engineering aspects of flow technology

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Introduction

Although continuous operations have been the mainstay of bulk chemical production for nearly a century (think sulphuric acid, ammonia, methanol, etc.), the chemistry-driven fine-chemicals industry has long been reluctant to follow suit. In the past decade, however, "flow chemistry" has captured the imagination of chemists, with many syntheses being demonstrated in continuous mode instead of in the traditional batch-stirred flasks [1]. This has sparked the interest of fine-chemical manufacturers in continuous (or flow) processing.

While many have already invested considerable effort and funds in flow processing, most fine chemical manufacturing is still conducted in the traditional batch mode in large, stirred vessels. The benefits of flow processing over batch are widely recognized by the US FDA, which has issued guidelines [2]. It will become increasingly untenable for manufacturers to continue in the business-as-usual practice of batch processing. Those who transition to flow earlier will reap the pioneers' premium through significantly increased safety, stable operations, intensified processing, and low variability, ultimately translating to higher profits and market presence. This article is written by workers intensely involved in batch-to-flow transitions. It aims to provide a realistic view of the benefits and challenges of transitioning and a generalized roadmap to effect such a transition.

Flow Philosophy

Flow processing is to batch processing what NASCAR [3] racing is to regular driving. Whereas a person can buy and drive a car with minimal training, NASCAR teams modify cars extensively for speed and control, and their drivers get intensively trained to get the most out of their machines. NASCAR design teams often include mechanical engineers with PhDs from the best universities in the world and get compensated at rates commensurate with their expertise.

Similarly, with batch processing, it is relatively quick to get production going with standard engineering solutions that have already been tried and tested over many decades and operated by staff who can mostly learn on the job. This is the great advantage of batch processing when rapidly putting products into the market or responding to changing market demands. A stirred vessel is a multipurpose reactor. Astonishingly, chemistries as varied as those involving n-butyl-lithium, Grignard synthesis, nitrations, hydrogenations, oxidations, leaching, and fermentation can be effected in practically the same reactor configuration. Thus, in batch processing, the chemistry is force-fit to the reactor.

Since most such fits are sub-optimal, considerable profitability gains are obtained by transitioning to a more specifically designed configuration. Flow processing substantially involves using a reactor designed around the chemistry, one of the main reasons it can win profitability gains that batch-processing cannot.

Flow processing requires considerably greater engineering inputs than a stirred-tank-based process: inputs not just from chemists and chemical engineers but also from mechanical engineers, instrumentation and control engineers, fabrication experts, and economic experts. Further, it tasks their expertise to the full since, at least to date, there have yet to be standard solutions. Each system must be designed from the ground upusing first principles.

Operating a flow process is much simpler and requires less manual intervention than the corresponding batch process. It allows tighter control of expenses, reliable and reproducible product specifications, and can give advance intimation of process "drift". Flow processes are in keeping with the "just in time" [4] philosophy that has so revolutionized automobile manufacturing. However, the supporting infrastructure must be meticulously maintained with little tolerance for electricity, utility, or equipment failures or drift in specifications of the raw materials. Further, the startup and maintenance-shutdown of such a process involve highly trained and experienced engineers to be on-site almost continuously for as long as a couple of weeks at a time and, given the opportunity cost of the halt in production, should be planned out in detail beforehand and executed flawlessly.

Transitioning to flow is more than just a matter of acquiring new technology or equipment. At the heart of it is a fundamental shift in the philosophy and culture of manufacturing, with a heavy emphasis on first-principles modelling, quantitative analysis,

planning, forecasting, and preventive maintenance. It further requires continuous, unfettered, and respectful communication between members of a multidisciplinary team who are constantly educating each other in their respective fields to develop integrated solutions to presented and anticipated problems.

When should you go for the flow?

The flippant answer to this question is "As soon as possible." There is a degree of truth to that. To maintain market competitiveness, manufacturers will eventually be forced into continuous processing, and there is no point fighting the inevitable. However, the transition needs must happen in stages, prioritizing those processes that would benefit most from flow.

Good candidate processes for flow have one or more of the following characteristics:

Inherent chemistry advantages of flow

An exemplary flow process would intrinsically benefit from flow processing over batch processing. An excellent example of such a reaction is nitration without sulphuric acid[5]. This occurs at higher temperatures where the nitric acid spontaneously forms the nitronium ion. However, the residence times of the order of a few minutes would be impossible to effect in a stirred tank where heating and cooling operations are 30-60 mins. Further more, a flow reactor can be configured with extended surfaces to provide the heat transfer area necessary to remove the reaction exotherm – which can only be done clumsily in a large batch reactor (e.g., using cooling coils).

Process Safety Reasons

It is well known that carrying out fast, exothermic reactions like nitrations, n-butyl lithium-based couplings, or Grignard synthesis in ~10 kL stirred vessels is a cumbersome, slow (since feed starvation is the primary means of temperature control), and highly hazardous (constant danger of reaction runaway) process with industrial incidents occurring with a daunting frequency. The operators of such transformations take their lives into their own hands every day of their working lives. Other reactions, such as amidations of fatty acids, need to be carried out at high temperatures and hence concomitantly high pressures (~ 100 bar) to contain the often volatile, amine reactants. Operating a 10 kL vessel at such pressures is not just capital intensive but a significant hazard due to the quantum of potential energy stored in the vessel, not to mention the inventory of the toxic amine.

The same processes in flow are far safer to operate primarily because of the low in-process inventory due to the much lower volume of the flow reactors, which significantly mitigates the risk of containment failure. The lower volume also means that the flow reactors can be built more robustly at a similar cost as the stirred tanks and can be put behind containment walls and shields cost-effectively.

Process Automation

Flow processes can readily be designed to preclude routine manual intervention completely. The operators' job is primarily to monitor and flag issues for preventive maintenance. With the advent of the Internet of Things, a flow process can be monitored remotely, facilitating communication between operators and plant managers. If a process has multiple points of human intervention, it might be an excellent candidate to transition to flow.

Utility Conservation

A less appreciated advantage of flow is the ability to install heat recovery units, which can decrease utility consumption by at least an order of magnitude compared to a batch process. Consider the transesterification of a triglyceride with glycerol, which is carried out at ~270°C. In a batch, the raw material (at ~30°C) would have to be heated to 270°C and cooled down again after the batch, resulting in a temperature swing of 240°C. In flow, a cross-heat exchanger can be installed to use the hot effluent stream to heat the cold feed stream. If the driving force for heat transfer is ~10K, the hot utility needs only raise the temperature of the feed from 260°C to 270°C, and similarly, the cold utility needs only to cool the effluent from 40 to 30°C.

The utility consumptions thus drop by a factor of 27!

All fluid systems with low residence times

Since pumping fluids is far easier to execute with standard, off-the-shelf technology than pumping solids or slurries, those processes that involve pumpable fluids as reactants are far easier to transition to flow and should be prioritized to benefit early from the transition. A lower residence time is also beneficial because it can reduce the size of the flow reactor.

Process Intensification with Temperature

If a process could be intensified by operating at a higher temperature or pressure, it is a great candidate for transition to flow. For example, n-butyl lithium based synthesis (normally carried out at cryogenic conditions in batch) can readily and safely be conducted at 0-5°C in a flow reactor with a very short residence time (10-30s). Similarly, nitrations that are normally carried out at 0-5°C to mitigate the exotherm, can be affected at ambient or higher temperatures with shorter residence times, greater selectivities and greater atom efficiencies.

Other considerations for batch to flow transitions

Note that difficult transitions to flow, including processes involving viscous slurries, abrasive solids, dry powders, long residence times, and molten materials, are still possible and often very much worthwhile. They present more difficult engineering challenges and have a longer lead time to commercialization. During this time, one of the above processes would have successfully transitioned and started yielding revenue.

An essential concern for fine chemical manufacturers is the seasonal demand for chemicals.

In this case, the strategic transition team should identify two or more processes, with anticipated campaign durations of at least three months, for transitioning to flow and design flow equipment that can be rapidly repurposed for one or the other of these. A multi-product flow system can be devised if one can envisage demand for multiple products. Intense manual involvement is only required during the transition between campaigns. This is operating in a campaign continuous mode.

The Roadmap to Flow

The roadmap to flow, as presented here, presupposes access to the aforementioned interdisciplinary teams. Suppose such a team still needs to be assembled. It is recommended to get the assistance of flow solutions providers such as Amar Equipment Pvt. Ltd., which have such teams and offer services at every stage of the batch-to-flow transition, from concept to commercialization.

The roadmap to flow has several way stations, from understanding the chemistry to full commercialization

Quantitative Understanding of Intrinsic System Behaviour

The very first way station is to develop a thorough understanding of intrinsic chemistry. This preferably involves the use of mathematical modeling and non-linear regression to determine rates of the primary and side reactions and temperature effects. Thermic effects and thermal and hydrodynamic properties of the reaction mass should be obtained or reasonably estimated at this stage.

Design and Simulation

Once all the kinetic and property parameters are in hand, it is necessary to invest time and effort in developing mathematical models of the process in its putative flow reactor. The scaling relationship governing hydrodynamics of the flow reactors, i.e., pressure drops, residence time distributions, heat transfer coefficients, and mass-transfer coefficients (in the case of multiphase systems), are already abstracted into correlations by the manufacturers of the reactors. Combined with the intrinsic system behavior, these can be incorporated into a reliable mathematical model of the system, which can be validated using small-scale experiments.

First Techno-economic Analysis

Based on the simulations, validated at small scales but extrapolated to commercial scales using the scaling relationships, a techno-economic evaluation of the commercial plant should be conducted *in silico*. This should involve all capital, raw material, utility, and other anticipated expenses and should be the input to a financial model whose results are trusted by the decision-makers. The capital expense includes reactors and ancillaries like pumps (typically among the largest sinks of capital), valves, pressure regulators, control and monitoring systems, etc. The financial analysis should be put before these decision-makers to get a go-no-go decision from them.

Piloting

In case of a "go" decision, the next step is piloting. The purpose of piloting is to validate the model on which the first techno-economic analysis was based. It is recommended that during piloting, the exact configuration of the reactors be used as in the final commercial system, except for smaller volumes or smaller numbers. For example, if 1-inch diameter tubular reactors are to be used in the commercial system, use 1-inch diameter tubes in the pilot – but with shorter lengths.

The following statement goes against the accepted industry wisdom – but we would like to lay it out anyway: there is really no need to demonstrate the same performance as in the commercial reactor, i.e., it is not necessary to demonstrate in the pilot the same conversions as in the commercial reactor. Instead, check if the model predicts the obtained conversions. If it does, further scaleup can be achieved with great confidence. If not, retrain the model on the pilot data and scale up with confidence. Manufacturers of flow reactors will offer assistance in piloting – from helping with modeling to building the full pilot skids. Another round of techno-economic and financial analysis can happen at this stage if necessary.

Commercial Plant

Once piloting is completed, the commercial plant's plans should be drawn up. Much of the work is already done during the techno-economic evaluation. The manufacturers of the flow reactors will often provide hand-holding and sometimes a guarantee on the performance of their reactors. The plant can be set up by one of several EPC contractors available on the market, in close coordination with the flow reactor manufacturer, since the EPC contractor will need details of the engineering aspects of the non-standard components forming the flow reactors.

Conclusion

In conclusion, flow operation offers many advantages over the business-as-usual manufacture in large stirred vessels. The process is more automated and reliable, monitoring is facile, and manual intervention is minimized. However, it makes many demands. It requires a thorough, quantitative understanding of the process and the equipment. It requires constant, respectful communication between members of a highly trained, motivated, multidisciplinary team to anticipate and forestall disruptions and plan and execute shutdowns and startups meticulously. It requires access to a good, knowledgeable fabrication partner.

While batch processing is the comfort zone for chemical manufacturing right now, the future is clearly in flow. Chemical manufacturers should start transitioning their processes to flow as soon as possible. This process begins with transitioning the culture in these organizations to one in which front-line workers, engineers, and technologists feel empowered to actively participate in the innovative process and feel secure enough to learn from colleagues with different background and skills.

References

1) Plutschack et al, Chem. Rev. 2017 https://doi.org/10.1021/acs.chemrev.7b00183

2) Q13 Continuous Manufacturing of Drug Substances and Drug Products | FDA

3) https://www.nascar.com/

4) Just in Time JIT Production; Benefits and Requirements (leanmanufacturingtools.org)

5) Nitration Chemistry in Continuous Flow using Fuming Nitric Acid in a Commercially Available Flow Reactor | Organic Process Research & Development (acs.org)

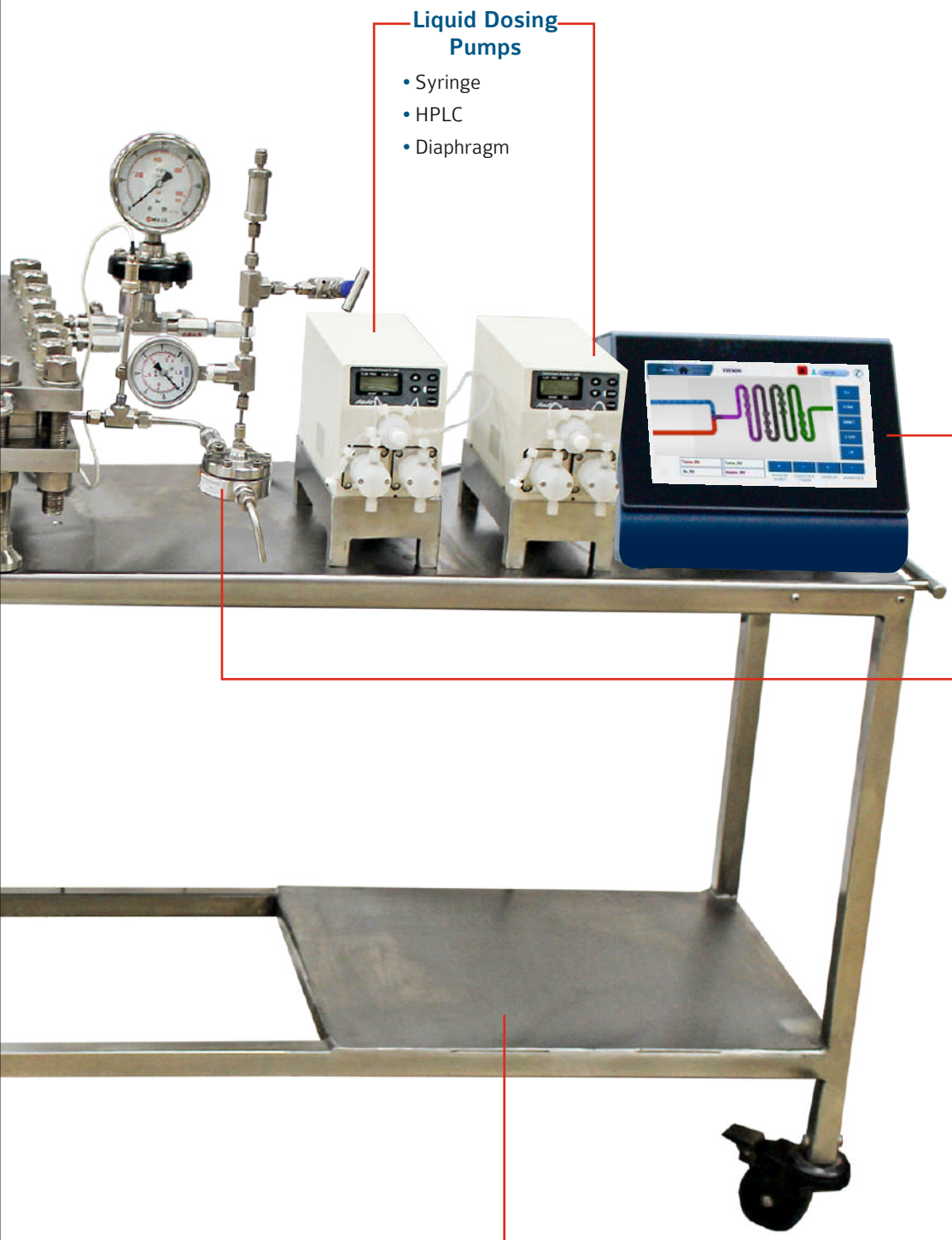
Example of Flow Reactor System

MicroFLO™ Reactor

- Material: SS316 or Hastelloy
- Inlets can be 2 or 3 depending on reagents / dosing points required

Heating Cooling Circulator

- Temperature -90 to 250 °C



Liquid Dosing Pumps

- Syringe
- HPLC
- Diaphragm

Control Panel

- Manual-PID
- Touch panel

Back Pressure Regulator

- MOC: PTFE, SS316, Hastelloy
- Option of manual, pneumatic or automatic control

Structure / skid

- Aluminium
- SS 304
- MS painted

LabFLO™ Reactor

Ideal for gas-liquid and liquid-liquid multiphase reactions

SALIENT FEATURES

- Screening tool for continuous flow feasibility studies
- Extremely effective mixing
- Very high heat transfer area
- Easy to clean - openable design
- Economical

TECHNICAL SPECIFICATIONS

Volume	1 mL micromixer & 10 mL residence coil
Flow Rates	Up to 6 LPH
Pressure	Up to 50 bar
Temperature	-50°C to 350°C
Material	SS-316, Hastelloy, etc.

APPLICATIONS

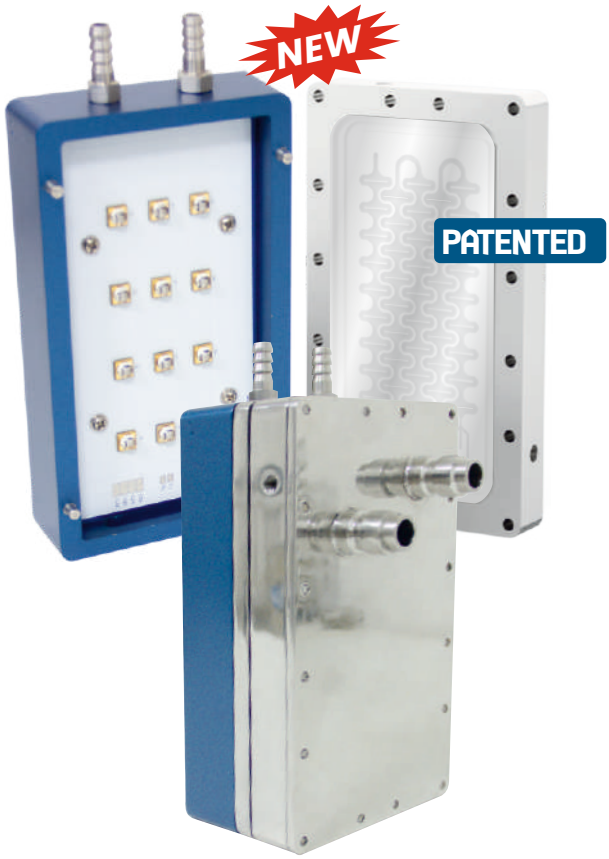
- Nitration, Halogenations, Sulfonation, Diazotization, Oxidation, Reduction, Lithiations, Grignard based chemistries.

PhotoFLO™ Reactor

Based on our compact, space-filling MicroFLO™ design, this reactor maximizes photon efficiency

SALIENT FEATURES

- LED illumination array (20-32W) available in at least four wavelengths (365, 385, 405, 415 nm) and additional filters can easily be accommodated.
- High heat and mass transfer rates of the patented MicroFLO™ design enhances safety and reaction yield.
- Built-in thermal interlock feature additional safety by automatically shutting down the system in case of overheating.
- Uniform photon distribution across the reactor volume



TECHNICAL SPECIFICATIONS

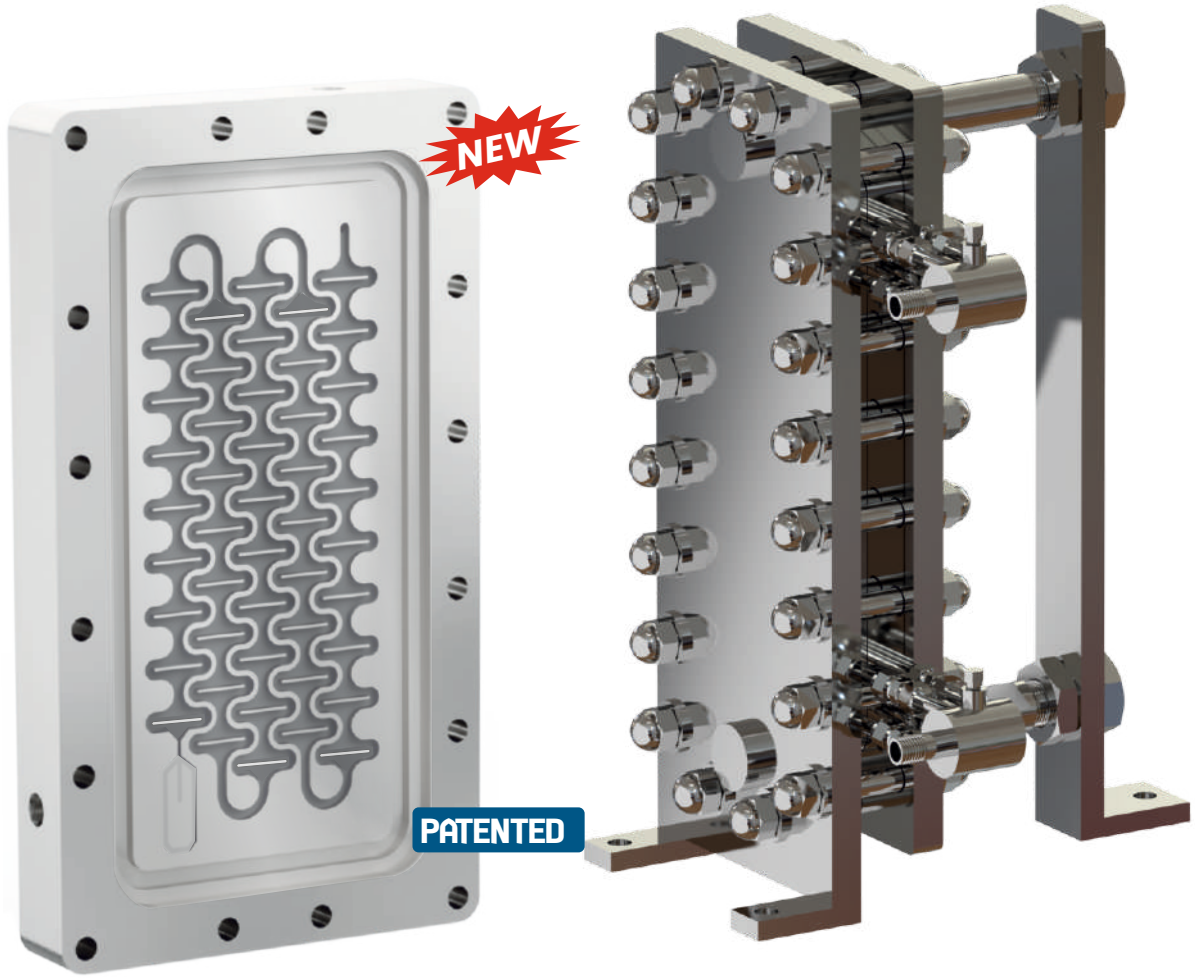
Volume	12mL to 200mL volume microchannel reactors
Flow Rates	Up to 10 LPH
Pressure	Up to 10 bar
Temperature	-20°C to 200°C
Material	SS316, Hastelloy C with front covering of glass

APPLICATIONS

- Photo-halogenations, Photo-alkylation, Photo-oxidation, Photolysis, Photo-Fries rearrangements

MicroFLO™ Reactor

Ideal for gas-liquid & liquid-liquid multiphase reactions



MicroFLO™ reactor is a compact plate type flow reactor with much greater surface area to volume ratio & heat transfer area than comparable reactors. This is achieved through our innovative space-filling patented design

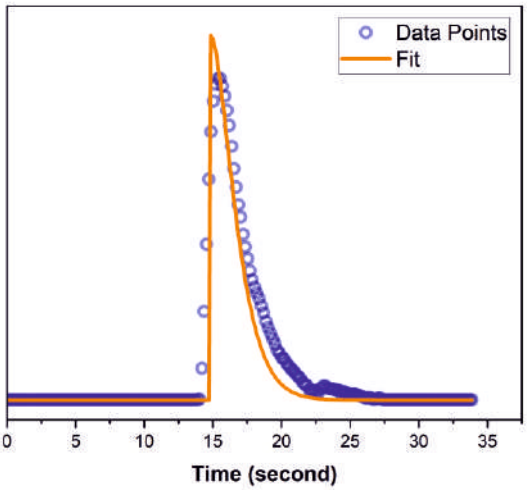
SALIENT FEATURES

- Patented microchannel design with alternate reactor & utility plates
- Modular design for easy scale-up from lab to production
- Very high specific surface area for effective heat transfer
- Openable design for ease of maintenance
- Alternate 3D printed fused design for very high heat transfer coefficient

TECHNICAL SPECIFICATIONS

Volume	5 mL to 2 L
Flow Rates	Up to 100 LPH
Pressures	Up to 100 bar
Temperature:	-50°C to 350°C
Material	SS-316, Hastelloy, etc.

Residence Time Distribution for MicroFLO™ Reactor



Exceptionally narrow residence time distributions ensures rigorous control on selectivity and conversion

APPLICATIONS

- MicroFLO™ reactor is exceptionally suited for fast-exothermic reactions where tight temperature control is essential for safety and selectivity

PinchFLO™ Reactor

The PinchFLO™ tubular reactor is ideal for liquid-liquid, gas-liquid exothermic reactions with high throughput at commercial scale

Pilot scale
1 - 10 kg/hr

Lab scale
0.5 - 1 kg/day

Lab scale 10 - 10,000 kg/hr

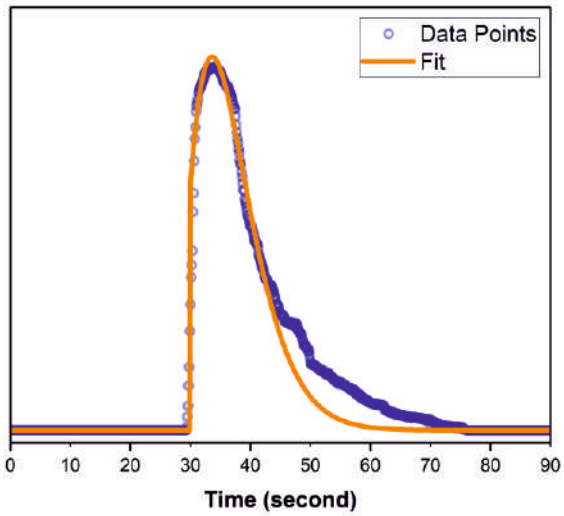
SALIENT FEATURES

- Patented pinched-tube design for effective mixing
- Pilot to plant scale flow reactor with different size pinch tubes
- High heat transfer surface area due to pinching
- Metric tons production capacity
- Most economical reactor in terms of cost / unit volume of reactor
- Double pipe, shell-and-tube jacket design

TECHNICAL SPECIFICATIONS

Volume	50mL to 1000L
Flow rates	Up to 10000 LPH
Pressure	Up to 100 bar
Temperature	-50°C to 350°C
Material	SS316, Hastelloy C, etc

Residence Time Distribution for PinchFLO™ Reactor



The reactor offers a narrow residence time distribution and superior mixing, outperforming traditional plain tubes

APPLICATIONS

- Nitrations, Oxidations, Organometalic chemistries, Sulfonations, Diazaotizations, Liquid-Liquid extractions, etc.

Static Mixer
TubularFLO™ & CorFLO™ Reactor

The CorFLO reactor is particularly suited for mixing-intensive processes at commercial scale

CorFLO™ Reactor

TubularFLO™ Reactor

SALIENT FEATURES

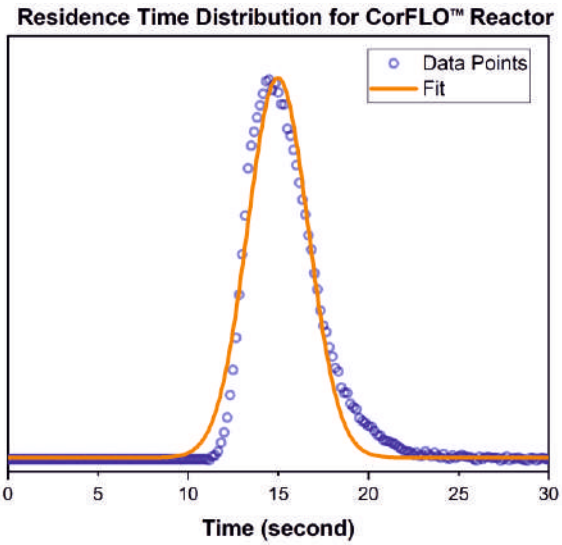
- Specially designed CorFLO™ tubes offer higher heat, mass transfer & lower pressure drop as compared to plain tubes
- Double pipe, shell-and-tube jacket design

TECHNICAL SPECIFICATIONS

Volume	50mL to 1000L
Flow rates	Up to 10000 LPH
Pressure	Up to 100 bar
Temperature	-50°C to 350°C
Material	SS316, Hastelloy C, etc

APPLICATIONS

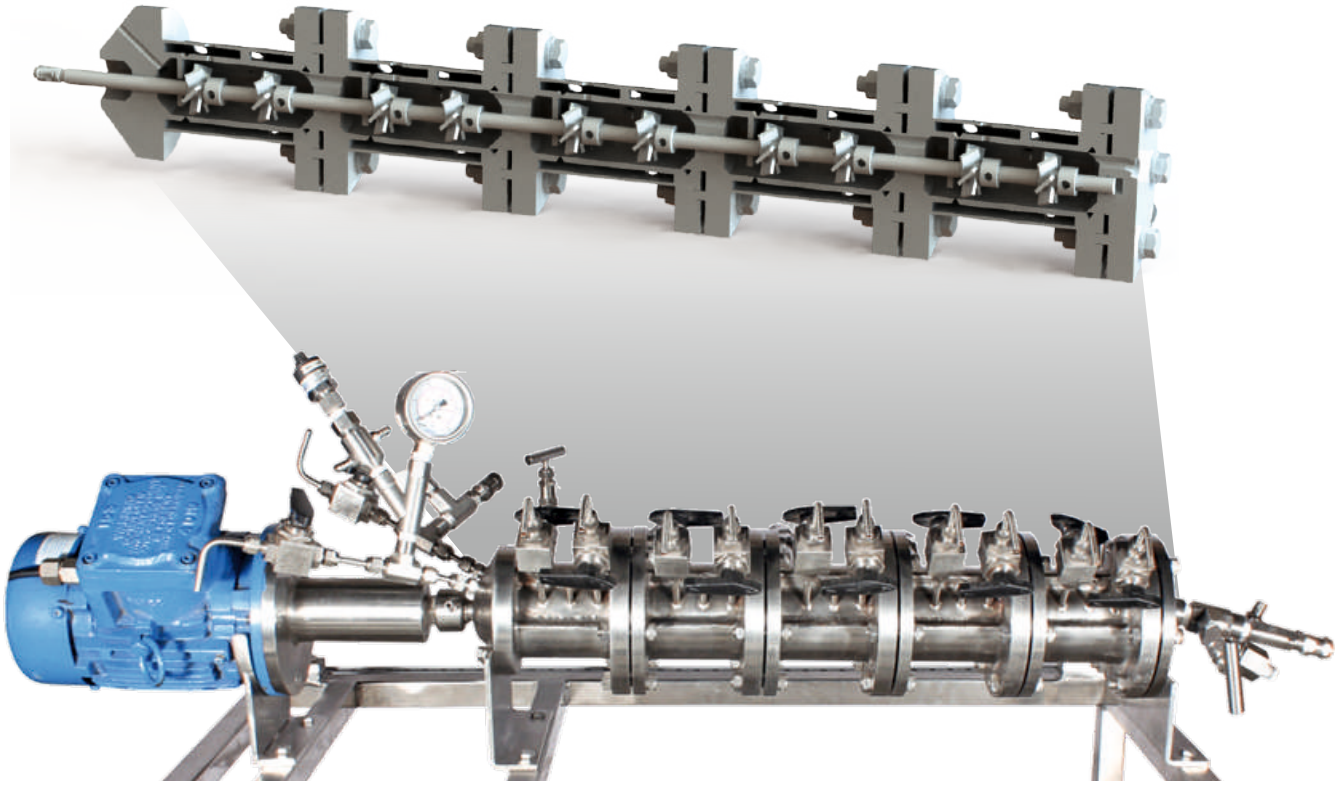
- Polymerization, blending of reagents, neutralization reactions, emulsification & bioprocessing.



The CorFLO™ reactor delivers narrow residence time distribution and superior mixing efficiency

SlurryFLO™ Reactor

The SlurryFLO™ Reactor is a versatile continuous reactor designed for performing reactions involving slurries



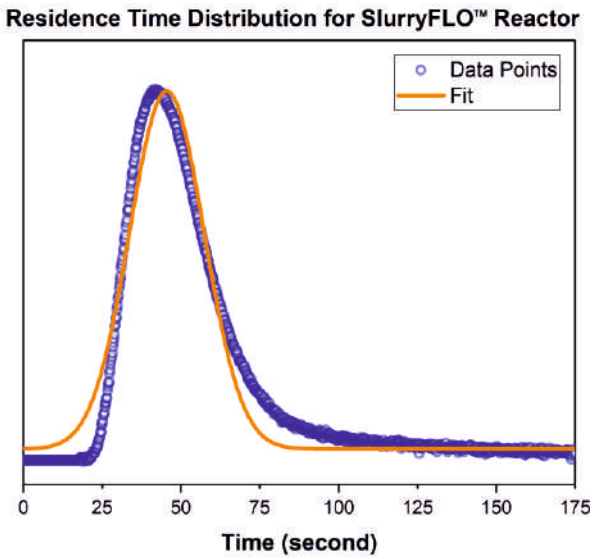
Each cell is equipped with impellers which help to disperse reaction media uniformly. Efficient slurry mixing helps distributing the heat generated during the reaction, prevents localized heating, and provides uniform temperature throughout the reactor.

SALIENT FEATURES

- Multiple jacketed reaction vessels connected in series horizontally with common magnetically coupled agitator
- It can handle clean fluids / immiscible fluids / slurry application or reactions with long reaction times

TECHNICAL SPECIFICATIONS

Volume	250 mL to 50 L
Flow Rates	Up to 300 LPH
Pressure Range	Up to 100 bar
Temperature Range	-30°C to 250°C
Material	SS316, Hastelloy C, Glass with Metal



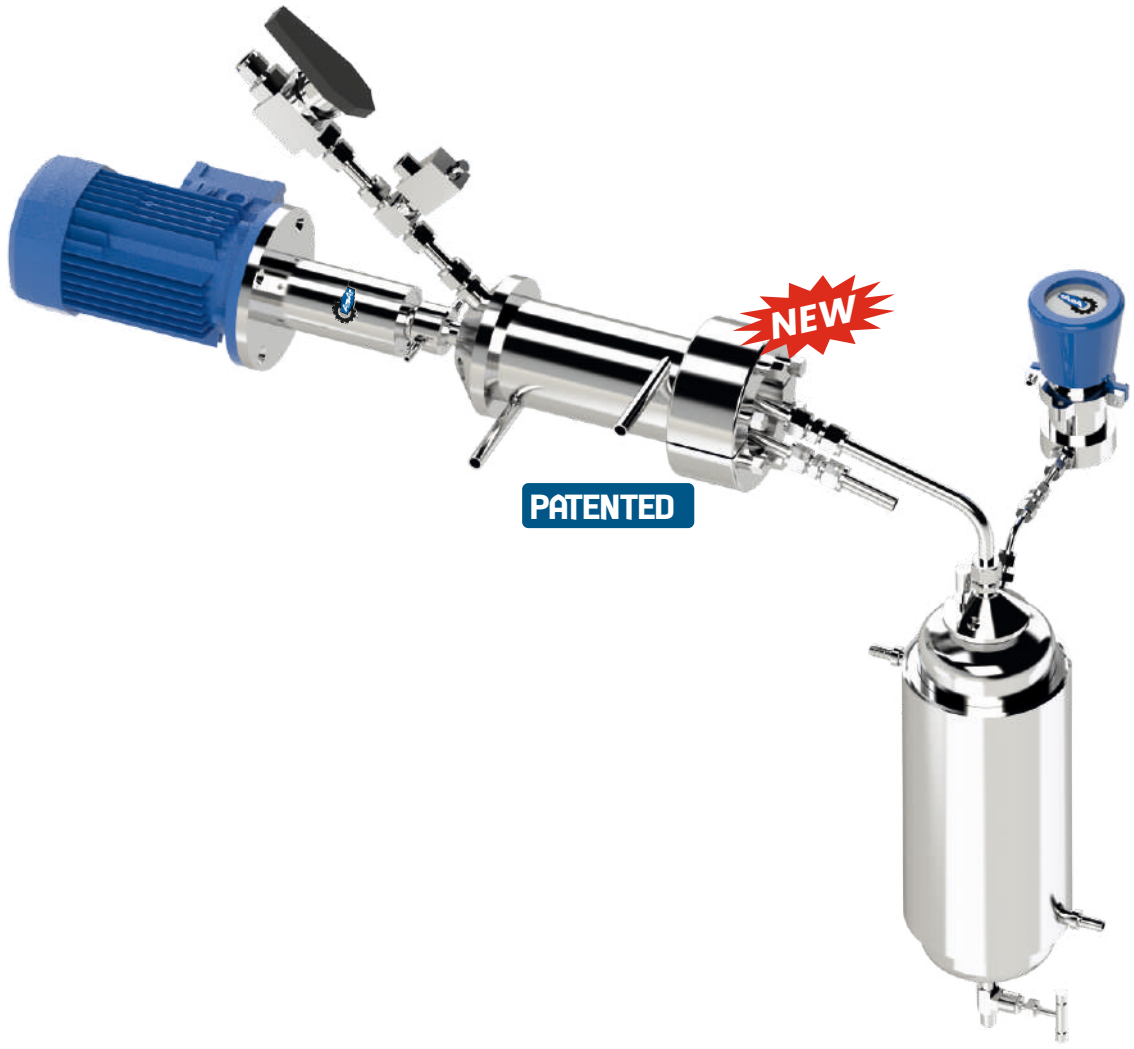
The reactor houses several cells of equal volume in series and thus closely approximates a plug flow reactor

APPLICATIONS

- Excellent for heterogeneously catalyzed reactions with finely disperse catalysts
- Reactions such as Hydrogenations, Nucleophilic substitutions, Aldol condensations, Esterifications
- Continuous crystallizations (evaporative/antisolvent/cooling) with uniform crystal-size distribution

MACFLO™ Reactor

The patented MACFLO™ reactor is a multipurpose reactor engineered for a variety of challenging flow applications



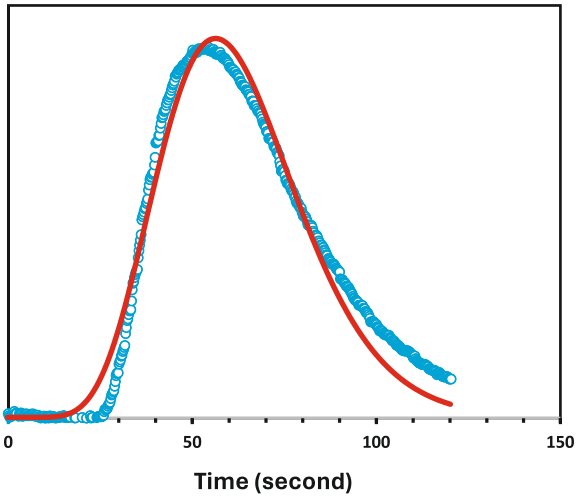
MACFLO™ - **M**ultiphasic **A**gitated **C**ontractor covers a wide range of flow reactions. Engineered for diverse chemistries, it excels in gas-liquid-solid reactions and processes that involve viscous fluids while demonstrating a plug-flow type behaviour.

Unleash innovation and efficiency in your research with the MACFLO™ reactor.

TECHNICAL SPECIFICATIONS

Volume	250mL to 50L
Flow rates	Up to 300 LPH
Pressure	Up to 350 bar
Temperature	-30°C to 350°C
Material	SS316, Hastealloy C, etc

Residence Time Distribution for MACFLO™ Reactor



It is an agitated horizontal flow reactor without partitions yet with very narrow residence time distributions almost exhibiting plug flow behaviour

APPLICATIONS

- Reactions involving slurries, viscous fluids, gas-liquid-solid contacting, fast exothermic reactions, long residence time reactions, and even continuous crystallizations

Continuous Stirred Tank Reactor

Single or multiple stirred reactors connected in series

SALIENT FEATURES

- Product is developed / produced on continuous basis for better productivity
- Single or multiple reactors connected in series
- Ex-proof system for hazardous area
- Fully automated PC controlled systems to continuously monitor, record & control various parameters like temperature pressure, motor speed, gas / liquid flow etc.
- Gas mass flow controller, metering pumps, level controller, catalyst filtration system with SCADA software etc. are provided for a typical hydrogenation application.

TECHNICAL SPECIFICATIONS

Volume	100mL to 1,000L
Pressure	Up to 350 bar
Temperature	Up to 500°C
Material	SS-316, Hastelloy, Inconel, Monel, Nickel, Titanium

APPLICATIONS

- Catalytic hydrogenation
- Saponification
- Fermentation
- Esterification
- Crystallization
- Various oxidation & reduction processes
- Polymerization
- Wastewater treatment

nanomake™

Microfluidic platform for nanoformulations

FEATURES

- Fully automated operation
- Single use and multi use microfluidic chip
- Wide range of flow rates on single platform
- Configurable 3 precursor pumps
- Built in washing program
- Interchangeable microfluidic chips of different internal volumes
- Easily replaceable 2mL, 15mL and 50 mL sample collection attachments
- Technical collaboration with ICT, Mumbai.

TECHNICAL SPECIFICATIONS

Flow rates	100 µL/min to 50 mL/min
Temperature	Ambient - 60°C (optional pre-heater)
No. of pumps (precursor)	3
Syringe sizes	500 µL, 1, 2.5, 5, 10 mL
Microreactor	Single use and multi use microreactor with different internal volumes
Nanomaterial synthesis	Lipid, Polymer, Metal
Controls	Total flow rate, flow ratio, sample volume, temperature

APPLICATIONS

- Liposomes
- MRNA lipid nanoparticles
- Drug loaded nanoparticles
- Metallic nanoparticles

Continuous Syringe Pump

Low-flow high pressure dosing pump for air-sensitive materials

FEATURES

- No contact of fluid with the wetted parts of the pump
- Can handle corrosive chemicals
- Pulseless pumping of the fluid

TECHNICAL SPECIFICATIONS

Flow rates	0.625 µl/min - 60mL/min
Pressure	Up to 20 bar

APPLICATIONS

- Grignard chemistry, lithiation reactions, other orgnometallic reactions, etc.

PascalFLO™ Pump

The patented PascalFlo's innovation lies in its ability to control the flow of the liquid /slurry without a flow meter on the liquid line

FEATURES

- Controlled dosing/pumping of any type of liquid or slurry, independent of temperature, rheology, composition of the fluid
- Accurate flow control without controllers on the liquid lines
- No need for recalibration of the system upon changing the liquid
- Practically pulseless pumping
- Operated by controlled gas flow

TECHNICAL SPECIFICATIONS

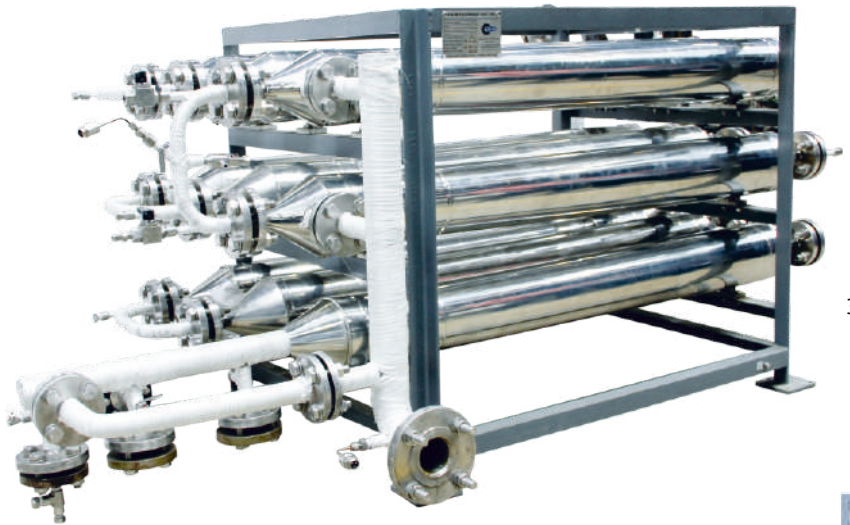
Flow rates	Range from 1mL/min up to 100LPH
Pressure	Up to 100 bar
Temperature	Up to 350°C
Material	SS316, Hastealloy C

Customised Flow Reactor Systems

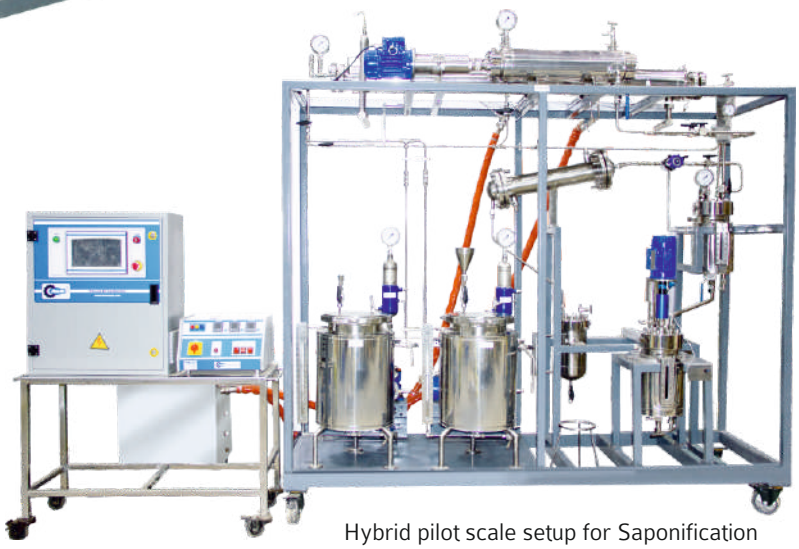
Complete turn-key solutions from lab to plant scale can be offered with desired design, safety & hazardous area certification.

TubularFLO™ reactor system

MicroFLO™ reactor skid with feed tanks, HPLC pumps & heating cooling circulators

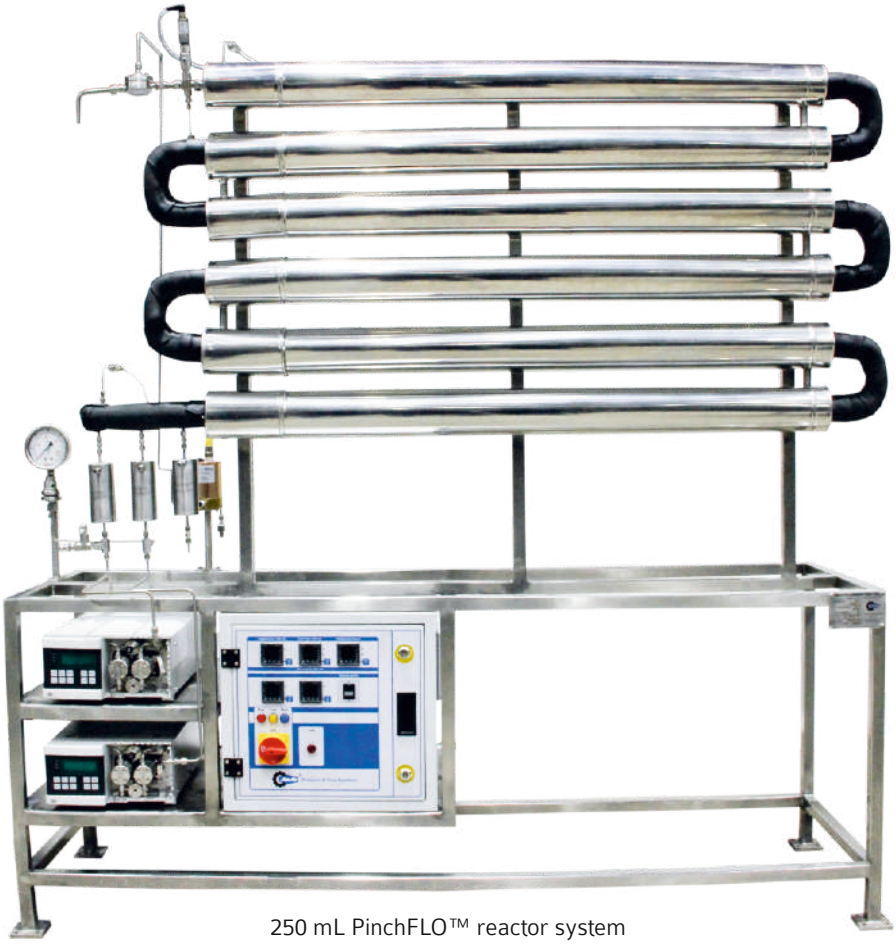


3L TubularFLO™ reactor with static mixer



Hybrid pilot scale setup for Saponification using 2.5L VishwaFLO™ & PinchFLO™ reactors

Customised Flow Reactor Systems



250 mL PinchFLO™ reactor system

50 mL MicroFLO™ microreactor
in series (2 nos.) with feed pumps

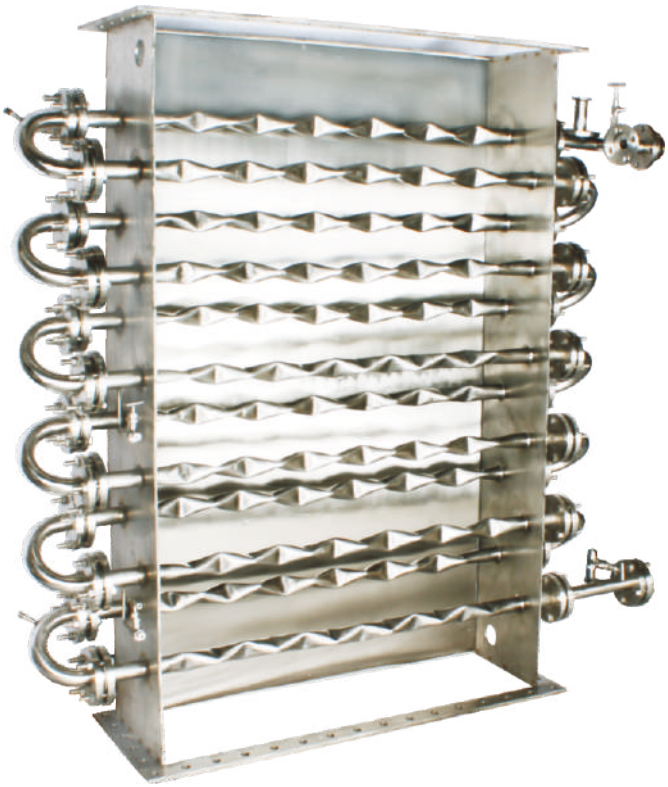
1L SlurryFLO™ reactor system

Scaled-up Flow Reactor Systems

Amar has expertise to design, manufacture & integrate commercial flow reactor systems with pumps, accessories, utilities, automation on a common skid up to 10,000 LPH for various applications.

2L TubularFLO™ reactor
for Nitration reaction
with 15 LPH throughput

10L TubularFLO™ reactor
for N-alkylation with
600 LPH throughput



12L PinchFLO™ reactor
for Neutralization 4 ton /
day throughput

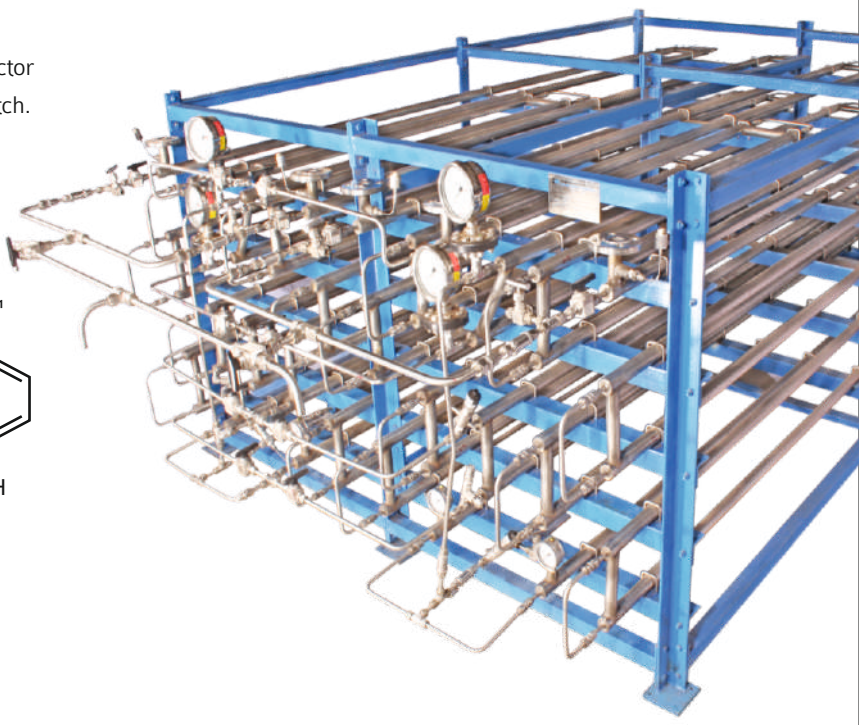
50L TubularFLO™ reactor
for decyclization at 1,000 LPH

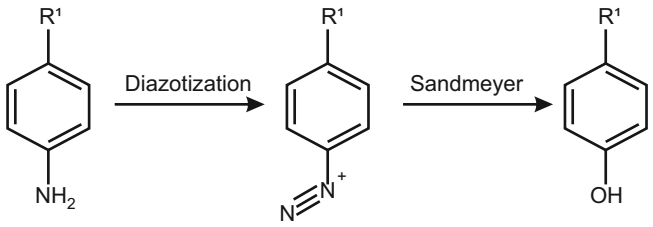
2L TubularFLO™ reactor
for Acetylation at 100 LPH

Scaled-up Flow Reactor Systems

DIAZOTIZATION FOLLOWED BY SANDMEYER REACTION

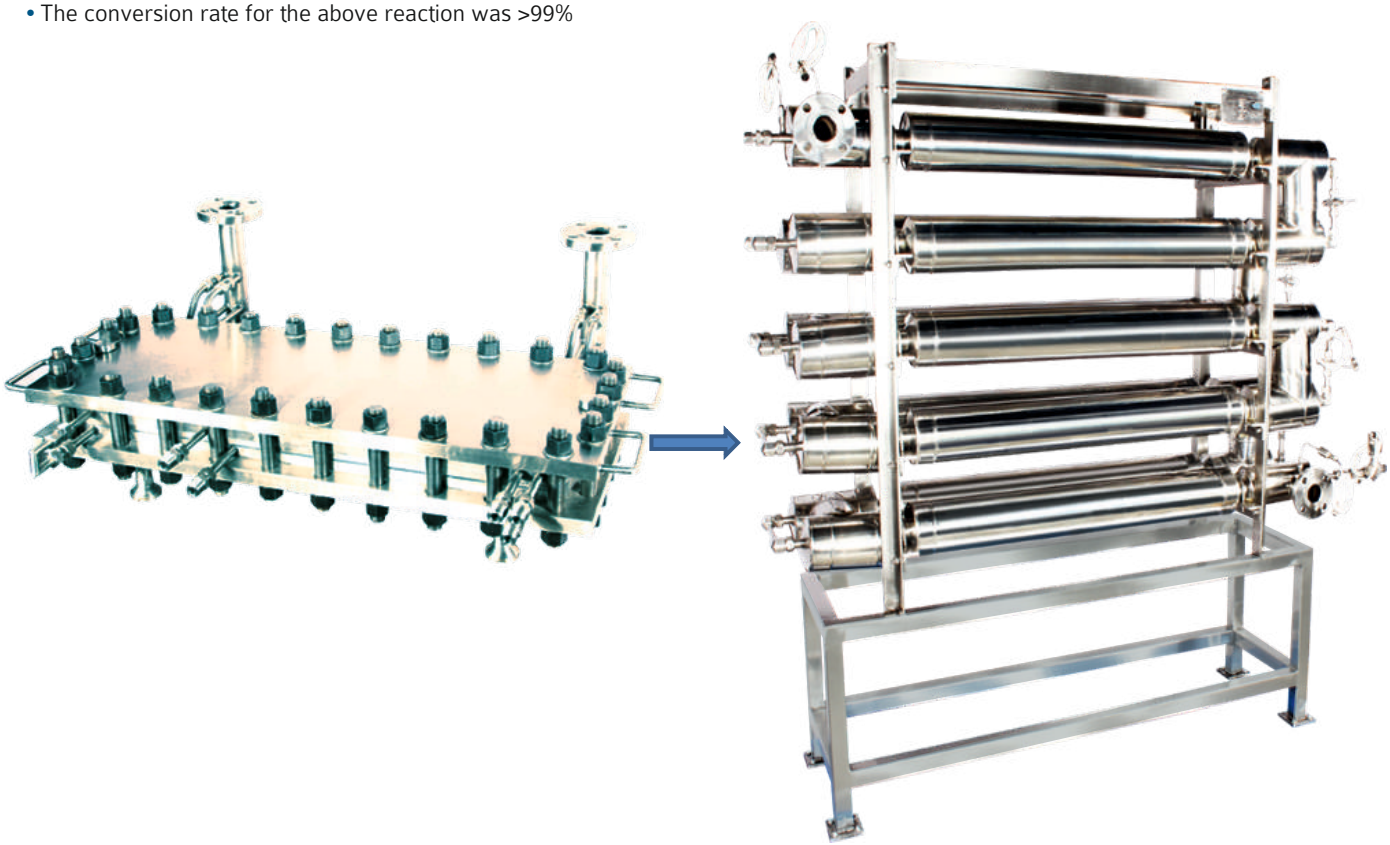
- The scale-up of the above operation was 50 kg/day.
- The conversion rate for the above reaction was >99%.
- It could handle up to 10% solid loading in TubularFLO™ reactor
- The selectivity for flow process was 75% against 30% in batch.





NITRATION REACTION

- Process for this nitration reaction was set using lab-scale MicroFLO™ & PinchFLO™ reactor in series
- MicroFLO™ takes out initial heat of reaction followed by PinchFLO™ reactor for residence time
- Similar residence times and product quality were observed from lab-scale to pilot-scale
- The scale-up of the above operation was successful at 9 ton/day using PinchFLO™ reactor of 4L
- The conversion rate for the above reaction was >99%



Scaled-up Flow Reactor Systems

AMINE CONDENSATION REACTION

- High value API with a final tonnage of 5000 TPA.
- Client observed high exotherm in their batch reactor, therefore decided to turn to flow for this API. We used PinchFLO™ reactor as shown below to demonstrate the feasibility.
- We observed reaction rates at elevated temperatures keeping the purity constant. Client performed trials at Amar Labs up to 4-5 kg/hr production rate and now has purchased a scaled up system for piloting capable of 60-80 kg/hr capacity.

Pilot scale stage 2
40 - 70 kg/hr

Pilot scale
1 - 10 kg/hr

Lab scale
0.5 - 1 kg/day

Batch Reaction		
• Molar ratio of Amine	:	12 equivalents
• Reaction Temperature	:	105°C
• Reaction Time	:	180 minutes
• Isolated Yield	:	~ 80 %

Flow Reaction		
• Molar ratio of Amine	:	8 equivalents
• Reaction Temperature	:	200°C
• Residence Time	:	5 minutes
• Isolated Yield	:	~ 80 %

Scaled-up Flow Reactor Systems

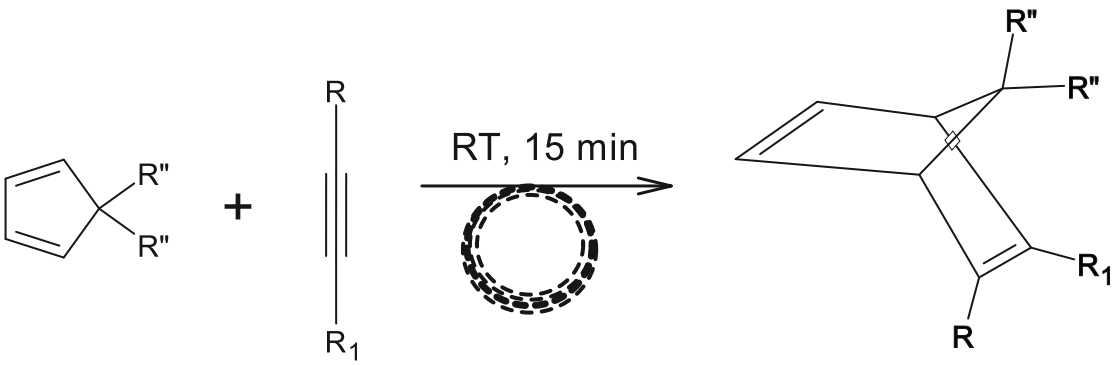
DIELS – ALDER REACTION IN FLOW REACTOR

- Low Volume High Value Intermediate, final tonnage about 40 TPA.
- Client used Alkyne reagent in gas phase in batch however, scale up to higher volume is challenging due to gas headspace, hence turned to flow for safety reasons.
- Currently demonstrated production of 0.1 TPA capacity using the TubularFLO™ reactor shown to the right, client requires direct scale up to commercial level up to 50L capacity.
- Improved Reaction rates at elevated temperatures keeping the purity constant.

Batch Reaction	
• Amount of solvent used	: 7 times wrt limiting reagent
• Reaction temperature	: 180°C
• Reaction time	: 60 minutes
• HPLC yield	: ~ 30 %

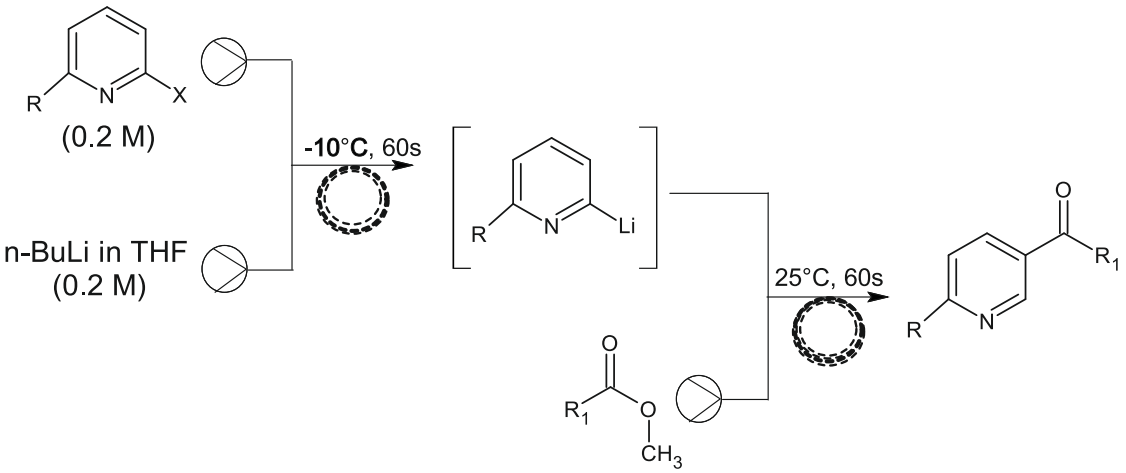
Flow Reaction	
• Amount of solvent used	: Less than 6 times wrt limiting reagent
• Reaction temperature	: > 230°C
• Residence time	: Less than 20 minutes
• HPLC Yield	: ~ 49 %

Cross section view of
TubularFLO™ Lab Scale Reactor



LITHIATION REACTION IN FLOW REACTOR

- Low-Volume-High-Value-Intermediate, final tonnage about 20 TPA.
- Client uses n-BuLi reagent and carries out the reaction in batch at subzero temperature around -60°C.
- Currently demonstrated production of 0.1 TPA capacity at -10°C using the MicroFLO™ reactor shown to the right, client requires direct scale up to commercial level up to 50L capacity.
- Improved reaction rates at elevated temperatures keeping the purity constant.



Fixed Bed Reactor System

SALIENT FEATURES

- Fixed, fluidized, trickle bed designs offered.
- Reactor volumes from 10mL to 100L.
- Designed up to 350 bar & 1000°C.
- SS316, Inconel, Hastelloy C etc.
- Explosion proof plants for hazardous area.
- Tabletop or skid mounted plants.
- Customisable systems for gas liquid feed combinations, series or parallel reactors, multi zone heating furnaces etc. with integrated controls, high level of safety, automation and SCADA software.

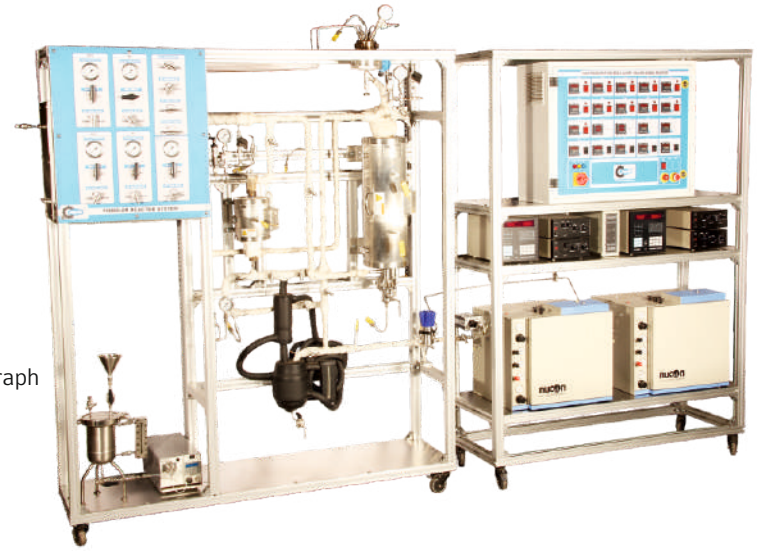
APPLICATIONS

- Catalyst screening
- Hydrogenation
- Fischer-tropsch process
- Hydro-cracking
- Vapor phase reaction
- Coal to syngas production
- Pyrolysis reactions
- Biomass gasification

- Micro reactor assembly for Liposome formation
- Reactor volume: 100 mL
- Pressure: 100 bar
- Temperature: 500 °C
- Material: Hastelloy C

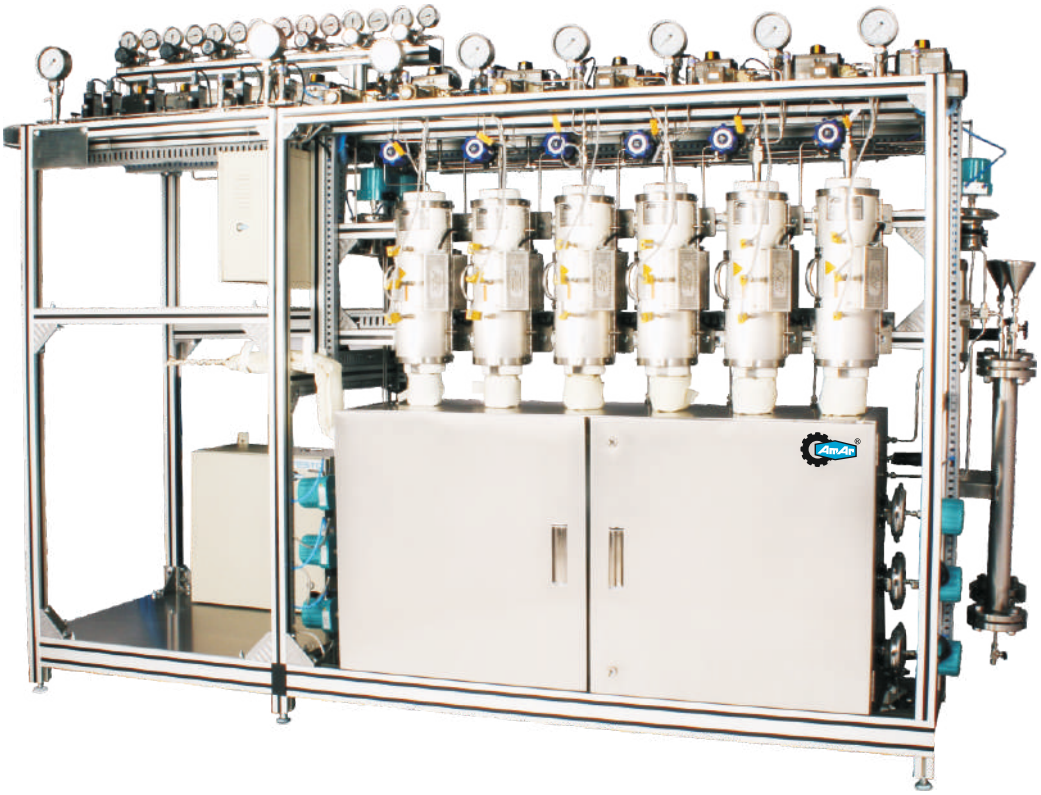
- 2 reactors with flexibility to connect in parallel & series
- Reactor volume: ~30mL
- Pressure: 5 bar.
- Temperature: 1000 °C.
- Materials: Inconel

Table Top Reactor System (TTRS)



- Reactors: 2 nos.
- Pressure: 100 bar
- Temperature: 700 °C
- With gas chromatograph

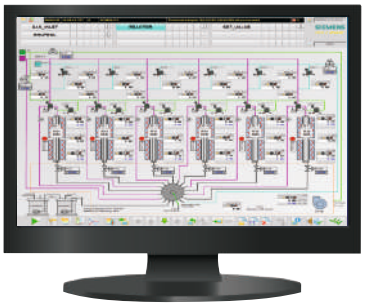
Fixed Bed Reactor System



High throughput multi tube reactor system for catalyst screening

SYSTEM SPECIFICATIONS

- Reactor volume: 6 Nos- parallel- 10 to 100mL same or of different volumes (optional: upto 16 nos in parallel).
- Design pressure: 100 bar
- Design temperature: 900 °C
- Material: SS 316, Inconel, Hastelloy C, etc.



Pilot scale tubular reactor with purge panels for continuous biojet fuel production

Example of Fixed Bed Reactor System

Gas Panel - MFC

- Thermal
- Coriolis

Control Panel

- Manual – PID
- PID + HMI screen (touch panel)
- PLC + SCADA

Structure Skid

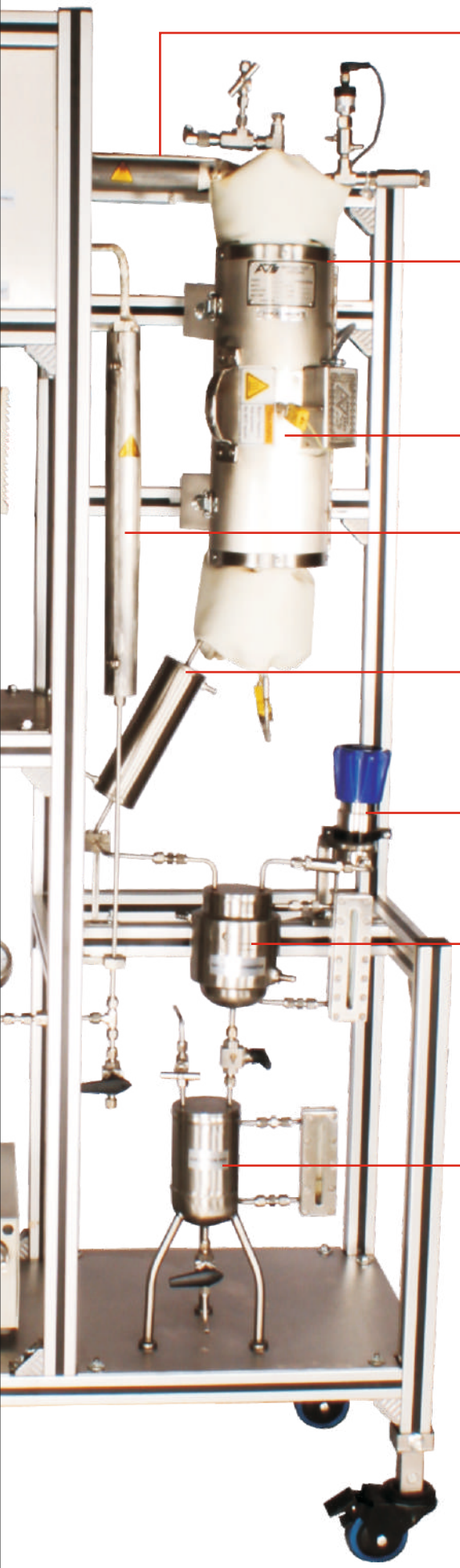
- Aluminium
- SS 304
- MS

Liquid Feed Vessel

- Ambient temperature
- High temperature - either jacketed or electric heating

Liquid Pump

- HPLC
- Diaphragm metering
- Syringe
- Gear
- Peristaltic



Pre Heater

- Heating with line heater / ceramic band heater

Reactor – Tubular with catalyst support

- Downflow
- Up flow
- Both up flow and downflow
- Multiple reactors in series / parallel

Furnace / jacket heating with thermic fluid

Vaporizer

- Heating with line heater / ceramic band heater

Condenser

- Spiral
- Double pipe
- Shell & Tube

Back Pressure Regulator

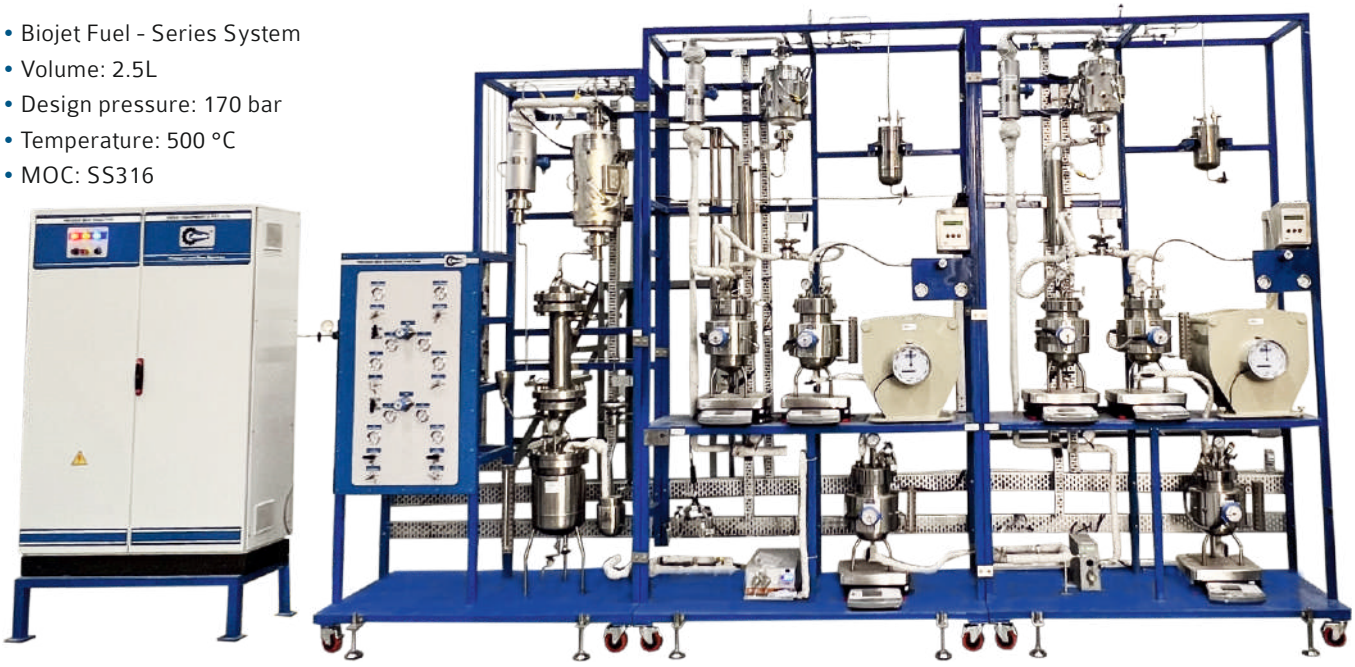
- Manual
- Automatic

Gas-Liquid Separator - Jacketed

Liquid Product Collection Vessel

Fixed Bed Reactor System

- Biojet Fuel - Series System
- Volume: 2.5L
- Design pressure: 170 bar
- Temperature: 500 °C
- MOC: SS316

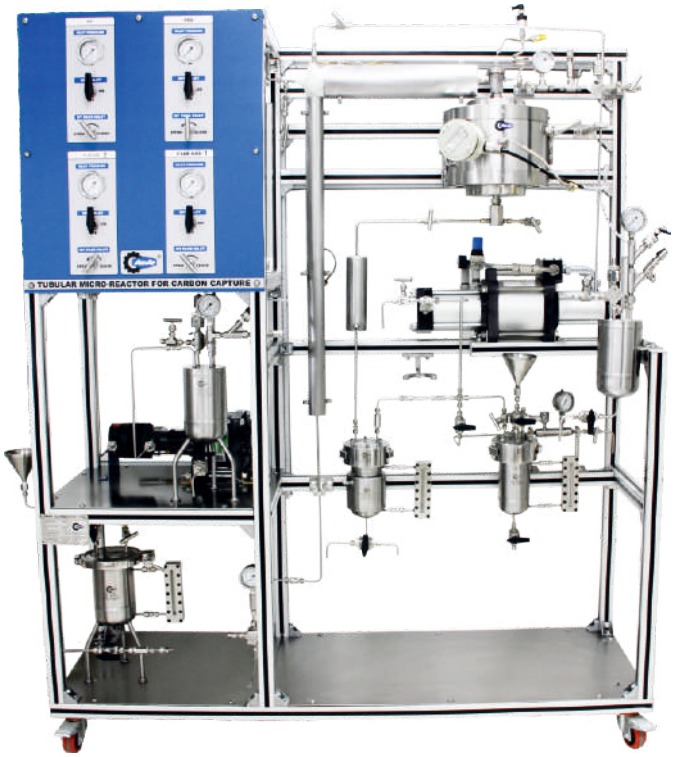


- Pilot plant vapor skid
- Volume: 3.5L
- Design pressure: 20 bar
- Temperature: 650 °C
- MOC: Nickel 201

- Simple vapor phase condensation reactor
- Volume: 1.5L
- Design pressure: 100 bar
- Temperature: 600 °C
- MOC: HC276

Fixed Bed Reactor System

- Carbon capture
- Volume: 50mL
- Design pressure: 30 bar
- Temperature: 600 °C
- MOC: SS316



- Vapor phase reaction
- Volume: 550mL
- Design pressure: 20 bar
- Temperature: 700 °C
- MOC: HC276

- Metal oxide reduction / oxidation
- Volume: 12L
- Design pressure: 20 bar
- Temperature: 600 °C

Fixed Bed Reactor System

Fixed bed plant - skid mounted nitrilation reaction lab setup for acetonitrile with two reactors in parallel configuration

- Volume: 5L
- Pressure: 5 bar
- Temperature: 500°C

Twin reactor setup with parallel configuration

- Reactor - 1, 500mL, 5 bar, 1100 °C, HC 276
- Reactor - 2, 500mL, 60 bar, 650 °C, HC 276
- Steam reforming & Fischer-Tropsch reaction

Fixed & Fluidized Bed Reactor System

Pilot Plant for Bio-fuel

- Reactor - 1, 600mL, 5 bar, 950 °C, Inconel 625
- Reactor - 2, 1700mL, 60 bar, 480 °C, Inconel 625

High pressure vapor phase hydrogenation system

100mL, 200 bar, 700°C, SS 316
skid with enclosure

Fluidized bed reactor

Volume 700mL, 10 bar, 1100 °C,
Inconel 625

- Fluidization of alumina

Fluidized Bed Reactor System

SALIENT FEATURES

- Volume: 500mL to 200L
- Pressure range: up to 12 bar
- Temperature range: up to 1050°C
- A fluidized bed reactor is a vertical cylindrical tube having 2 sections i.e., reaction section & disengagement section.
- Even temperature distribution throughout the burning zone, while solid catalyst particles are freely suspended using gas of high velocity.
- Product is collected from top & solid residue collected from the bottom.
- Solid feed: Batch/Continuous.
- Uniform particle mixing.
- Uniform temperature gradients.
- Catalyst/solid can be fed from top/bottom while gas/liquid is fed from the bottom.
- Explosion proof plants for hazardous area.

APPLICATIONS

- Conversion of coal-derived products
- Syngas generation
- Pyrolysis reactions
- Biomass / coal gasification reactions
- Conversion of gaseous reactants into fuels
- Liquefaction reactions, etc.

Pyrolysis reactor system
Hybrid system of fixed & fluidized bed

Fluidized Bed Reactor System

- Process: Air-blown fluidized bed gasification
- Gauge pressure: 10 kg/cm²
- Design temperature: 1000 - 1050 °C
- Gasification rate: 60 - 150 kg/hour
- Gasifier
- Coal feeding system
- Gaseous reactant supply system
- Bottom ash extraction system
- Cyclone with fly ash collection system
- Gas cooling and cleaning system
- Exhaust system and flare stack

Fluidized Bed Reactor System

- Design pressure:- 5 Bar
- Design temperature:- 1000°C
- MOC:- Inconel 625

Gas panel - MFC

- Thermal
- Coriolis

PLC based control panel

- Manual – PID
- PID + touch panel
- PLC + SCADA

Liquid feed vessel

- Ambient temperature
- High temperature - either jacketed or electric heating

Liquid pump

- HPLC
- Diaphragm metering

Reactor with furnace assembly

Condensers
- Double pipe
- Shell & Tube

Wet gas meter
- Manual
- Automatic

Gas liquid separator - jacketed

Structure / skid
- Aluminum
- SS 304
- MS

Product collection vessel

Heating Cooling Circulators

Thermostats for 10mL to 3,000L reactors

- Single fluid closed loop circulators: -90 °C to 250 °C.
- Heating cooling circulators: -70 °C to 175 °C.
- High temperature circulators: Ambient to 350 °C.
- Chillers: Up to -15 °C.
- CE marked units & NATURAL refrigerant optional
- With accurate programmable temperature controller & touch panel

Heating Cooling Circulators

Model	Temperature range C	Heating power in Kw	Cooling power in Kw @					*Pump flow lpm	Maximum pressure bar	HTF end connection	Dimensions mm	Supply voltage	Maximum current	Machine version	Cooling water flow and pressure
			0°C	-20°C	-30°C	-40°C	-60°C								
isoTHERM series (-90 to 250°C) closed loop heating cooling circulators															
CLM-1	-30...+200	1.5	0.6	0.3	0.1	—	—	18~20	0.3	M-24	475x400x800	1-ph 230 VAC	10A	Air cooled	—
CLM-2	-40...+250	2.5	0.8	0.5	0.25	—	—	30~35	0.4	M-24	420x520x875	3-ph 420 VAC	10A	Air cooled	—
CLM-3	-40...+250	3.6	1.2	0.7	0.3	—	—	30~35	0.4	M-24	450x600x900	3-ph 420 VAC	12A	Air cooled	—
CLM-4W	-45...+250	4.5	2.5	1.3	0.6	—	—	40~45	0.7	M-42	540x650x1250	3-ph 420 VAC	15A	Air cooled	250 lph/3 bar
CLL-1	-75...+200	1.5	0.6	0.6	0.6	0.6	0.3	30~35	0.4	M-24	600x650x1400	3-ph 420 VAC	15A	Air cooled	—
CLL-2	-75...+200	3	1.5	1.5	1.5	1.4	1.2	30~35	0.4	M-24	600x650x1400	3-ph 420 VAC	18A	Air cooled	—
CLL-3W	-75...+200	4.5	2.2	2.2	2.1	2	1.4	40~45	0.7	M-42	700x750x1500	3-ph 420 VAC	20A	Water cooled	250 lph/3 bar
CLL-4W	-90...+200	4.5	2.2	2.2	2.1	2	1.4	40~45	0.7	M-42	700x750x1501	3-ph 420 VAC	20A	Water cooled	250 lph/3 bar
CPM-1W	-45...+250	6	4	2.2	1.3	—	—	50~55	1	M-42	560x650x1300	3-ph 420 VAC	15A	Water cooled	400 lph/3 bar
CPM-2W	-45...+250	9	7	3.5	1.8	—	—	50~55	1	M-42	600x690x1300	3-ph 420 VAC	35A	Water cooled	700 lph/3 bar
CPM-3W	-45...+250	12	12	6	3	—	—	80~90	1.5	M-42	700x750x1500	3-ph 420 VAC	50A	Water cooled	1200 lph/3 bar
CPM-4W	-45...+250	18	15	7	3.5	—	—	80~90	1.5	M-42	750x790x1500	3-ph 420 VAC	50A	Water cooled	1500 lph/3 bar
CPL-1W	-60...+250	6	6.5	6.5	6.5	3.2	1	50~55	1	M-42	750x790x1500	3-ph 420 VAC	40A	Water cooled	650 lph/3 bar
CPL-2W	-60...+250	9	12	12	12	6	1.5	80~90	1.5	M-42	750x790x1500	3-ph 420 VAC	50A	Water cooled	1200 lph/3 bar
CIM-1W	-45...+200	21	25	11	8	—	—	100	1.5	M-42	1200x950x1600	3-ph 420 VAC	65A	Water cooled	2500 lph/3 bar
CIM-2W	-45...+200	33	45	21	12	—	—	120	2	M-42	1400x950x1800	3-ph 420 VAC	75A	Water cooled	4500 lph/3 bar
CIM-3W	-45...+200	45	70	30	17	—	—	120	2	M-42	1800x1000x1600	3-ph 420 VAC	95A	Water cooled	7000 lph/3 bar
CIM-4W	-45...+200	66	90	45	24	—	—	120	2	M-42	2000x1200x2000	3-ph 420 VAC	110A	Water cooled	9000 lph/3 bar
uniTHERM series (-70 to 175°C) heating cooling bath circulators															
HCB-1	-25...+175	1	0.4	0.2	0.05	—	—	14~16	0.4	M-16	300x500x650	1-ph 230 VAC	8A	Water cooled	—
HCB-2	-25...+175	2	1.1	0.7	0.3	—	—	14~16	0.4	M-16	420x560x1000	1-ph 230 VAC	12A	Air cooled	—
HCB-3	-25...+175	3	1.5	1	0.45	—	—	30~35	0.7	M-24	510x620x1050	3-ph 420 VAC	8A	Air cooled	—
HCL-1	-70...+100	1	—	0.4	—	0.3	0.2	14~16	0.4	M-16	610x700x1150	1-ph 230 VAC	15A	Air cooled	—
HCL-2	-70...+100	2	—	1.1	—	0.8	0.4	14~16	0.4	M-16	610x700x1150	1-ph 230 VAC	20A	Air cooled	—
HCL-3	-70...+100	3	—	1.5	—	1.4	0.6	30~35	0.7	M-24	700x700x1300	3-ph 420 VAC	15A	Air cooled	—
hiTHERM series (ambient to 350°C) high temperature circulators															
HTC-1	Amb...+350	3	Through internal cooling coil					30~35	0.7	M-24	410x410x700	1-ph 230 VAC	18A	—	—
HTC-2	Amb...+350	6	Through internal cooling coil					30~35	0.7	M-24	600x600x900	3-ph 420 VAC	12A	—	—
HTC-3	Amb...+350	12	Through internal cooling coil					50~55	1	M-42	900x900x1100	3-ph 420 VAC	22A	—	—
Penguin series (ambient to -15°C) chillers															
			0°C	-10°C											
CHL-1	Amb...-15	—	0.35	0.15	—	—	—	12~14	0.3	M-24	330x370x550	1-ph 230 VAC	6A	Air cooled	—
CHL-2	Amb...-15	—	0.7	0.3	—	—	—	12~14	0.3	M-24	360x460x600	1-ph 230 VAC	8A	Air cooled	—
CHL-3	Amb...-15	—	1.2	0.6	—	—	—	25~30	0.5	M-24	550x650x700	1-ph 230 VAC	12A	Air cooled	—
CHL-4	Amb...-15	—	2.4	1.5	—	—	—	30~35	0.6	M-24	450x650x1150	3-ph 420 VAC	6A	Air cooled	—
CHL-5	Amb...-15	—	4.5	2.5	—	—	—	30~35	0.6	M-24	700x700x1200	3-ph 420 VAC	8A	Air cooled	—
CHL-6	Amb...-15	—	10	6	—	—	—	55~60	1	M-24	1300x800x1600	3-ph 420 VAC	25A	Air cooled	—
CHL-7	Amb...-15	—	15	8	—	—	—	55~60	1	M-24	1500x950x1700	3-ph 420 VAC	32A	Air cooled	—
CHL-8	Amb...-15	—	20	12	—	—	—	80~90	1.5	M-24	1650x1100x1600	3-ph 420 VAC	45A	Air cooled	—

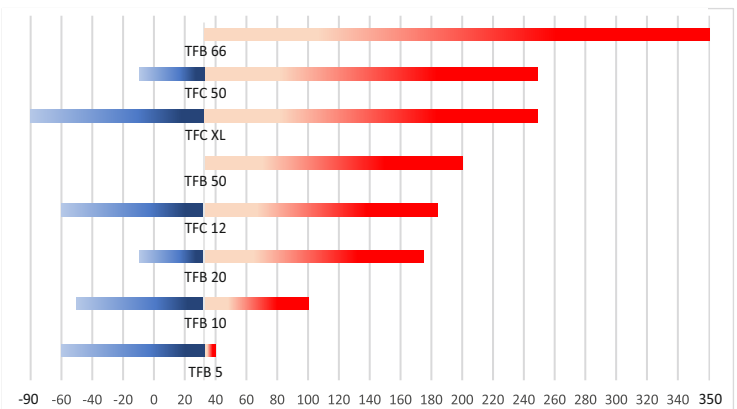
Note:

- Suffix "W" in model is for water cooled machine
- The given cooling power is at 35°C ambient temperature
- The temperature range mentioned above is at outlet of the machine
- Custom built models on request, as per process requirement
- In hiTHERM series, machines with higher heating capacity & ex-proof version on request

ACCESSORIES

- Insulated hose pipes
- Thermic fluid
- SCADA software & remote control
- Pressure booster pump
- Purge panel for ex-proof zone

Thermic fluid temperature chart



Optional Accessories

GAS PRESSURE REGULATOR

To manually charge different gases at desired pressures upto 140 bar / 2000 psi or higher into the reactor from gas cylinder. Nitrogen, Oxygen & Hydrogen can be charged through same regulator (with special adaptor). The regulator is made from SS316 & comes with inlet - outlet pressure gauges & flexible SS braided PTFE high pressure hose pipe (4m long) with check valve.

THERMAL GAS MASS FLOW METER (MFM) / CONTROLLER (MFC)

MFM can be used to measure accurate mass flow rate of gas (in gm/hr or LPH) & totalized quantity of mass / volume (in gms/ltr) charged in the reactor at any point. Mass flow controller (MFC) is used to charge the set flow rate of gas into the reactor at high pressures upto 100 bar. The same MFM / MFC can be used for multiple gases by just entering the conversion factor for different gas densities provided the gases are inert to each other. The MFM/MFC comes with high pressure flexible hose, inlet filter with digital gas flow indicator.

MFC

Flow Indicator & Totaliser

CORIOLIS GAS - LIQUID MASS FLOW METER / CONTROLLER

These are used for higher & accurate gas or liquid flow rate indication or control in cases where thermal mass flow meters are not suitable. A common meter can be used for different gases & liquids for a particular range of flow.

Coriolis Mass Flow Meter

Coriolis Mass Flow Controller

DIGITAL PRESSURE INDICATOR

It consists of SS316 / Hastelloy C pressure sensor (transmitter) & digital pressure indicator/ controller (mounted on common control panel) with pressure alarm.

Pressure Sensor

LIQUID METERING PUMP SYSTEM

This system is used to charge liquid at a desired rate from as low as 1mL/hr to 100L/hr, is under pressurized condition.

a) High pressure accurate HPLC type low flow metering pumps for high pressures upto 350 bar & flow range from 0.01 up to 100ml / min. Materials: SS316, option: Hastelloy C, Titanium

b) Diaphragm metering pumps for pressures upto 100 bar & minimum flow range of 60-600 ml/hr to maximum 10-100 lit/hr. The flow rates are varied by varying the motor speed with variable frequency drive. Materials: SS316, option: Hastelloy C, Titanium

(a)

(b)

WEIGHING BALANCE

To measure precise amount / quantities of feed / product consumed or produced during process.

FLOW CONTROL VALVES

These valves are used to control flow, pressure or level

Optional Accessories

BACK PRESSURE REGULATOR

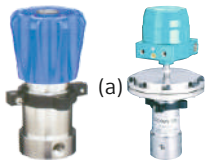
It is SS 316 regulator mounted on the vent line of the reactor & is used for maintaining constant pressure inside the reactor upto 350 bar. The pressure is maintained by releasing the excess pressure into the atmosphere.

Optional: a) Electronic actuated digital pneumatic back pressure regulator, (6 bar air supply is set digitally & can be released at preset rate of pressure release required).

b) Pneumatically actuated pilot operated back pressure regulator (air / N_2 gas supply for rated pressure is required)

c) Electronic control unit & forward regulator with 4 mtr. hose for activating (b) above.

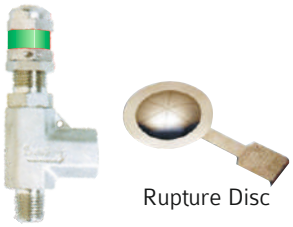
d) Materials: Hastelloy C, PTFE etc.


(a)


(b)

PRESSURE SAFETY VALVE & SAFETY RUPTURE DISC

Safety rupture discs can be provided for pressure ratings of 100 bar & pressure safety valves can be provided for any pressures from 1 to 350 bar with provision to vary release pressure within a certain range. These valves come with PTFE / Viton / Kalrez 'O' rings.


Rupture Disc

Pressure Safety Valve

SCADA SOFTWARE FOR REMOTE OPERATION & RECORDING

SCADA is a supervisory control & data acquisition software with all controllers / indicators having RS 485 modbus communication port or PLC & HMI / touch panel, for online display, set point changes & data logging of various parameters like pressure, temperature, liquid / gas flow rate, oil/heater temperature, level, pH, ORP, IR etc. remotely from PC as well as locally from panel. It gives continuous online data logging at predefined (variable) time interval, online graphical representation as well as historical data & graphs on PC for single or multiple autoclaves. RS 485-232 convertor & cable upto 50 m or higher is also supplied.

PURGE CABINET

Cabinet with nitrogen purging for explosion proof zones can be offered by mounting nonexplosion proof instruments & assembly inside the cabinet

WET GAS METER

Wet gas meter is an analog instrument used to measure exhaust gas flow for gas mixer & is available in all flow rate ranges. It can give output for digital flow indication

CONTROL PANEL

Control panel consists of programmable PID temperature controller cum indicator with temperature alarm system (settable), safety alarm & heater trip system for malfunctioning of controller / sensor/ temperature rise beyond set limit. Digital pressure indicator / controller, gas / liquid flow indicator, totaliser, level etc. indicators are provided additionally on same common control panel depending on the optional accessories selected.

Optional:

a) Touch screen panel with SCADA software.

b) PLC based control panel with touch panel HMI or remote SCADA software & PC control.


(a)


(b)


(c)

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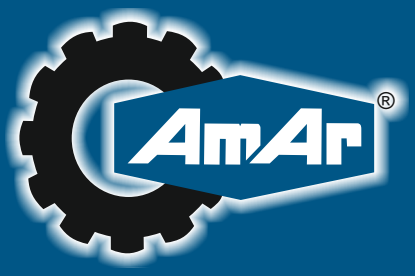
Sulfoxidation Fischer-Tropsch **Grignard**
Amoxidation **Diazotization** Liquefaction

Our Valued Clients



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