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EUROPEAN ROADMAP OF PROCESS INTENSIFICATION

- TECHNOLOGY REPORT -

TECHNOLOGY: ADVANCED PLATE TYPE HEAT EXCHANGERS

TECHNOLOGY CODE: 1.1.1

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1. Technology

1.1.1 Description of technology / working principle

(Feel free to modify/extend the short technology description below)

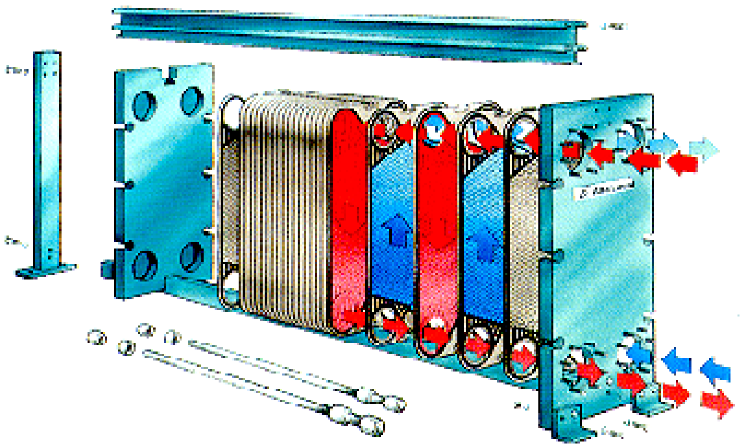
Plate exchanger consists of a pack of corrugated metal plates with portholes for the passage of two fluids between which heat transfer will take place.

1.2.1 Types and "versions"

(Describe the most important forms/versions of technology under consideration, including their characteristic features, differences and similarities)

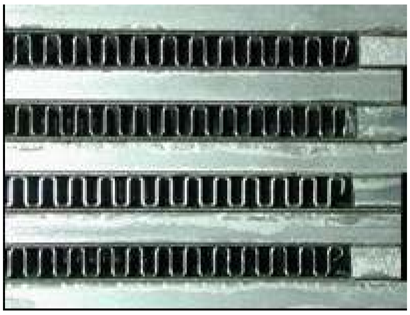
The plate pack is assembled between a pressure plate and a frame plate and compressed by tightening bolts. The plates are fitted with gaskets, which seals the channels and directs the fluids into alternate channels (Fig.A). Basic advantages of the plate heat exchangers are compactness, large heat transfer areas and high heat transfer coefficients. For applications where gaskets are undesirable (high pressure and temperature or very corrosive fluids), semi-welded or totally welded heat exchangers are available. A welded heat exchanger cannot be opened, and fouling will limit the range of application. Originally the first application was agro and now we have many applications in (petro)chemical and heavy duty off-shore.
Plate-fin exchanger consists of stacked corrugated sheets (fins) separated by flat plates with openings for the inlet and outlet of fluids (Fig.B) This type also called brazed aluminium are used in cryogenic applications like LNG and air separation processes. Flow direction of each of the fluids relative to one another may be counter-current, co-current or cross-flow.
In plate-and-shell heat exchangers bundle of plates are inserted in a shell (Fig.C). On the plate side, the fluid flows inside corrugated or embossed channels; on the shell side, the flow is similar to shell and tube heat exchangers, and baffles can be inserted. These exchangers are often used for revamping applications, as the shell can be kept identical as for a bundle of tubes.
Flat tube-and-plate heat exchangers have been developed in the automobile industry for engine cooling and air conditioning. Generally on the air side the surface is finned (plain or louver fins – Fig.D) and on the other side the fluid flows in small diameter channels.

ILLUSTRATIONS:



Flow pattern in a plate heat exchanger.

Figure A



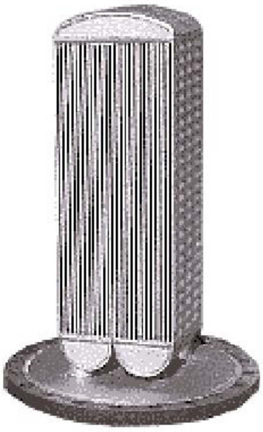


Figure B Figure C Figure D

1.1.2 Description of technology / working principle

(Feel free to modify/extend the short technology description below)

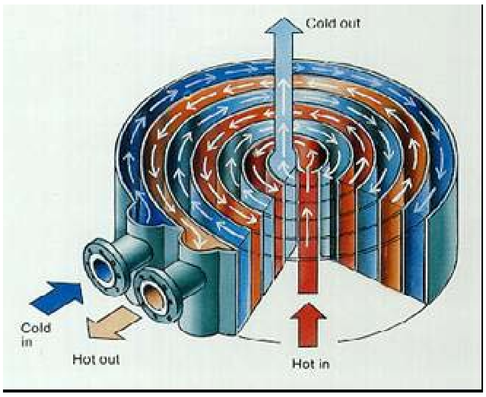
Spiral Plate exchanger consists of metal plates spiralised dividing the two heat transfer fluids.

1.2.2 Types and "versions"

(Describe the most important forms/versions of technology under consideration, including their characteristic features, differences and similarities)

In spiral heat exchanger the hot fluid enters at the center of the unit and flows the inside outward. The cold fluid enters at the periphery and flows towards the center. Passages can be either smooth or corrugated general flow configuration can be crossflow (single or multipass) or counterflow depending on the configuration of the inlet and outlet distribution boxes. Compactness is the most important advantage of spiral heat exchangers: 100 m2 of effective surface is contained in a spiral element 1 m in diameter and 1.5 m long. High turbulence, low fouling and easy access are further advantages of the spiral units. Design pressure limit is 20 bar.

ILLUSTRATION:



1.1.3 Description of technology / working principle

(Feel free to modify/extend the short technology description below)

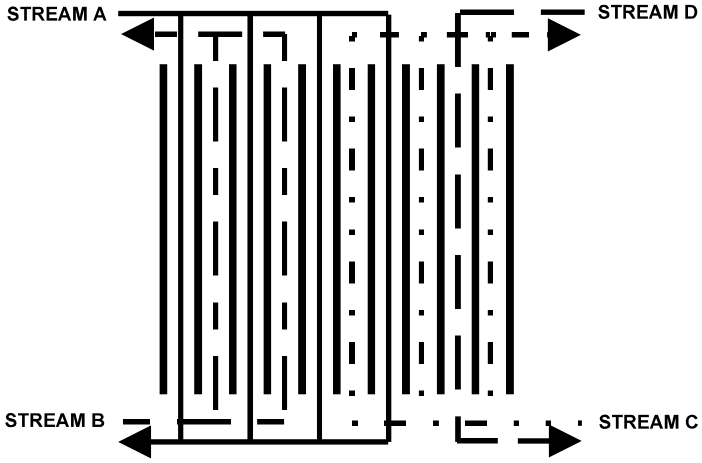
Plate exchanger consists of a pack of corrugated metal plates with portholes for the passage of multiple fluids between which heat transfer will take place.

1.2.3 Types and "versions"

(Describe the most important forms/versions of technology under consideration, including their characteristic features, differences and similarities)

In multi-stream heat exchangers three or more streams are thermally processed in a single unit. These exchangers have been used in cryogenic plants and in diary industry. In chemical industries they have been rarely applied so far. The multi-stream configuration can easily be achieved in the conventional plate heat exchangers, simply by installation of an intermediate plate on which the ports have not been cut out. Multi-stream units allow for further integration of chemical plants.

ILLUSTRATION:



Scheme of a four-stream plate-and-frame unit

1.1.4 Description of technology / working principle

(Feel free to modify/extend the short technology description below)

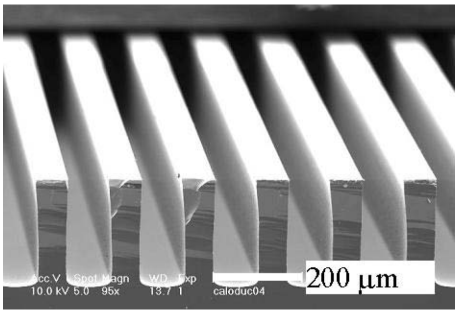
Micro-channel Plate exchanger consists of a pack of corrugated metal plates with portholes for the passage of two or multiple fluids between which heat transfer will take place.

1.2.4 Types and "versions"

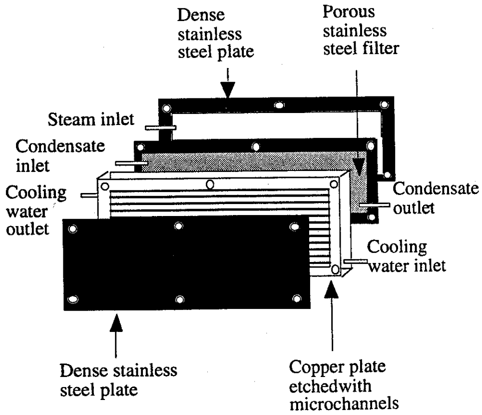
(Describe the most important forms/versions of technology under consideration, including their characteristic features, differences and similarities)

The channels in the micro heat exchanger plates have sizes around or lower than 1 mm and are fabricated via silicon micromachining, deep x-ray lithography or non-lithographic micromachining (Fig. A, B). The plates are stacked forming 'sandwich' structures. All flow configurations (co-, counter-current and crossflow) are possible. The basic limitations of microchannel heat exchangers are: sensitivity to clogging and pressure drop which is roughly inversely proportional to channel diameter.
Matrix heat exchanger consists of a stack of perforated plates made of high thermal conductivity material such as copper or aluminum, alternating with spacers of low thermal conductivity such as plastic of stainless steel. They are used for cryogenic and low temperature applications and for fuels cells, and are suitable for a large range of operating conditions (Fig.C).

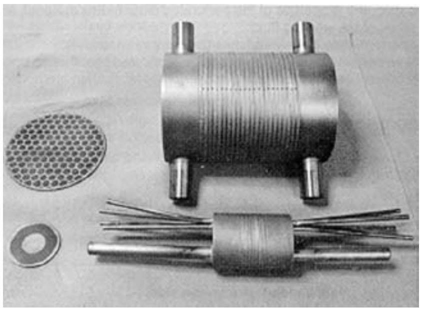
ILLUSTRATIONS:



(A) Silicium deep etching micro-channels (CEA)



(B) Components of the plate and frame microchannel heat exchanger for countercurrent flow.



(C)

1.3 Potency for Process Intensification: possible benefits

(In Table 1 describe the most important documented and expected benefits offered by the technology under consideration, focusing primarily on energy; CO_2 emission and costs, providing quantitative data, wherever possible. Add other benefits, if needed).

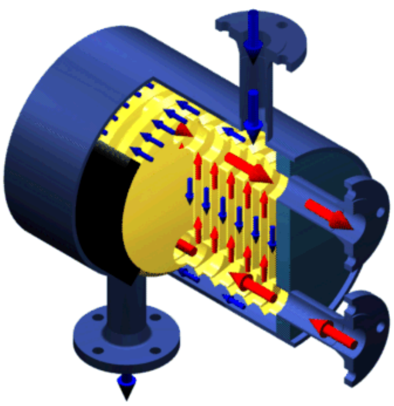
Table 1: Documented and expected benefits resulting from technology application

Benefit	Magnitude	Remarks
Energy Savings	30 to 50%	All Plate Type Heat exchangers have a tendency to foul much less than shell & tube heat exchangers. Turbulent flow regime is achieved at low flowrate. High convergence ratio heat transfer/pressure drop
Less CO2 emission	30 to 50%	See remarks above, and spiral plate type has embedded a self cleaning mechanism.
Cost Saving	Up to 1000%	All Plate Type Heat Exchangers can be designed with less heat transfer area.
Safety		Plate Type heat exchangers shall be used within their mechanical design limits. Some types are sensitive to cycling operation. Types provided with gasket are sensitive for leaking. Gasket made of special rubber like EPDM or VITON needs to be replaced frequently at least once every 3 years. Smaller inventory of chemical fluid. Lower retention time than Shell & Tube type.
Fouling		Plate Type Heat exchangers do operate much faster in turbulent regime than comparable Shell & Tube types. Normally a higher turbulence works anti-fouling. Wide gap plates are recommended are recommend for fiber containing fluids. Spiral Plate type work according a self-cleaning principle. Plate types with too small port holes are sensitive for fouling.
Maintenance		Plate Type exchangers with gasket and Spiral types are easy to maintain. Brazed types and diffusion bonded types can operate safely with clean fluids only.

1.4 Stage of development

All Plate Type heat exchangers are fully matured. Existing profiles like Herringbone structure is challenged to further improve ratio heat transfer/pressure drop.

Different types are entering the market. Vatherus with Plate in Shell is combining the advantages of a shell and tube type together with plate and frame. This is made from circular plates welded together.



2. Applications

2.1 Existing technology (currently used)

(Describe technology (-ies) that are conventionally used to perform the same or similar operations as the PI-technology under consideration)

Etched plate technology used by Heatric UK was introduced for heat exchanger application. Now it is being considered to be used as micro-channel reactor.

2.2 Known commercial applications

(Is the technology broadly applied on commercial scale? In which process industry sectors is the technology most often applied: large volume chemicals – specialty chemicals & pharma – consumer products – ingredients based on agro feedstocks? What is the estimated number of existing applications? In Table 2 provide the most prominent examples of realized applications and provide their short characteristics)

All Plate Type Heat Exchanger Types have been broadly applied on commercial scale in various processes.

Table 2. Industrial-scale applications of the Technology (existing and under realization)

Sector	Company - Process/Product name/type	Short characteristic of application	Production capacity /Plant size	Year of application	Reported effects
Chemical	Many End Users				•
Petro	Many End Users				
Pharma	Many End Users				
Food	Many End Users				

2.3 Known demonstration projects

(Are there any demonstration projects known related to the technology under consideration? In which process industry sectors are those projects carried out: large volume chemicals – specialty chemicals & pharma – consumer products – ingredients based on agro feedstocks? In Table 3 provide the short characteristics of those projects.)

All mentioned Plate Type Heat exchangers are matured technologies so demonstration projects are covered by numerous life plant examples.

Table 3. Demonstration projects related to the technology (existing and under realization)

Sector	Who is carrying out the project	Short characteristic of application investigated, including product name/type	Aimed year of application	Reported effects
				•

2.4 Potential applications discussed in literature

(Provide a short review, including, wherever possible, the types/examples of products that can be manufactured with this technology)

The literature concerning the potential applications of Plate type heat exchangers is very rich. Petro – Chemical, Utility, Pharma and Food examples are overwhelming. Plate and Frame, Spiral Plate are more often used in heavy duty oil refining application and FPSO's.
Plate Fin type, are being considered to replace large LNG kettles shell tube type of 6 meter diameter 60 meter long. Core in Kettles is the next step to reduce size.
However each Plate Type should be applied within their own mechanical pressure and temperature range.

3. What are the development and application issues?

3.1 Technology development issues

(In Table 4 list and characterize the essential development issues, both technical and non-technical, of the technology under consideration. Pay also attention to "boundary" issues, such as instrumentation and control equipment, models, etc.) Also, provide your opinion on how and by whom these issues should be addressed)

Table 4. Technology development issues

Issue	Description	How and by whom should be addressed?
Engineering & Design	Plate and Frame exchangers are originally used in milk applications. Manufacturers have developed different plate types from washboard, Herringbone to composite structures. Plate Fin type also brazed type aluminium type is used in cryogenic services. Spiral Plate Type is often used in applications like slurry and fouling fluids. Each vendor have developed their own correlations for pressure drop and heat transfer.	Vendors
Modelling	HTRI has developed software (X-PHE) to check-rate different vendor plate and frame types and spiral plate type. HTFS has developed MULE and MUSE software to model different plate fin types.	www.htri.net
Control	Proper control is required to operate plate types. For Plate and Frame type used for cooling high viscous liquids with open cooling water operate in winter condition may lead to local "freezing" effect. For Plate Fin, brazed aluminium types, and etched type like Heatric, are sensitive for temperature shock. Internal leakage is possible after cycling operation. Spiral Plate can be sensitive for cycling operation. Welded studs which ae needed in order to keep the plate distance, can protrude the plate leading to internal leakage. Spiral plate are used as (reflux) top condensers and lead to space and weight reduction.	

3.2 Challenges in developing processes based on the technology

(In Table 5 list and characterize the essential challenges, both technical and non-technical, in developing commercial processes based on the technology under consideration. Also, provide your opinion on how and by whom these challenges should be addressed)

Table 5. Challenges in developing processes based on the technology

Challenge	Description	How and by whom should the challenge be addressed?
Distribution problem in Plate and Frame Type	Flow distribution for large plate surfaces is a point of concern. Flow needs to be proper distributed from a port hole area to square area.	Various vendors develop different plate shapes to improve the flow distribution
Etched type compact plate type like Heatric	Heatric is being investigated to work as micro reactor	ECN
Plate Fin Type used in HIDIC	C2 splitter applications to reduce column height.	TUD
Plate Fin Type used in Cold Box	LNG liquefaction process is making use of this type and resulted in compact scale LNG Snohvit Core in Kettles.	Linde/Statoil
Plate & Frame Plate in Shell	The high conversion rate heat transfer / pressure drop this type can be seen as a good static mixer and can keep small bubbles in dispersion.	Vendors

4. Where can information be found?

4.1 Key publications

(Provide the list of key publications in Table 6)

Table 6. Key publications on the technology

Publication	Publication type (research paper/review/book/ report)	Remarks
K. M. Bailey. Understand spiral heat exchangers. *Chemical Engineering Progress* 1994 (May):59-63, 1994.	Paper	
K. M. Bailey. Plate heat exchangers- A compact Heat Exchanger Technology. Anonymous. Anonymous. 1997.	Paper	
S. Deshpande. Spiral Heat Exchangers. *CEW* XXVIII (2):81, 2007.	Paper	
A. Heierle. Static Mixer-Heat Exchanger. *CAV* 1989, 1989.	Paper	
M. Picón-Núñez and R. Flow Passage Arrangement and Surface Selection in Multistream Plate-Fin Heat Exchangers. *Heat Transfer Engineering* 26 (9):5-14, 2005.	Paper	
S. K. Ramesh. Advances in Science and Technology of Compact Heat Exchangers'. *Heat Transfer Engineering* 27 (5):3-22, 2006.	Paper	

R. K. Shah. Advances in Science and Technology of Compact Heat Exchangers. *Heat Transfer Engineering* 27 (5):3-22, 2006.	Paper	
P. Stehlík and W. Different Strategies to Improve Industrial Heat Exchange. *Heat Transfer Engineering* 23 (6):36-48, 2007.	Paper	
B. Thonon and P. Tochon. Compact multifunctional heat exchangers: A Pathway to Process Intensification. In: *Reengineering the chemical plant - Process Intensification*, edited by A. Stankiewicz and J. A. Moulijn, New York - Basel:Marcel Dekker, 2004,	Paper	
B. Thonon and P. Tochon. Compact multifunctional heat exchangers: A Pathway to Process Intensification. In: *Reengineering the chemical plant - Process Intensification*, edited by A. Stankiewicz and J. A. Moulijn, New York - Basel:Marcel Dekker, 2004,	Paper	
J. van Reisen, P. J. T. Verheijen, and G. T. Polley. Potential benefits of using compact multi-stream heat exchangers in integrated process plants. BHR Group Conference Series Publication. Anonymous. Anonymous. 83-93, 1995.	Paper	
V. V. Wadeker. Compact heat exchangers. *CEP* 2000 (december), 2000.	Book	
J. H. Wang. Use of plate heat exchangers in refinery and petrochemical plants. 2007.	Paper	
L. Wang and S. Design Methodology for Multistream Plate-Fin Heat Exchangers in Heat Exchanger Networks. *Heat Transfer Engineering* 22 (6):3-11, 2001.	Paper	

4.2 Relevant patents and patent holders

(Provide the list of relevant patents in Table 7. Under "remarks" provide, where applicable, the names/types of products targeted by the given patent.)

Table 7. Relevant patents

Patent	Patent holder	Remarks, including names/types of products targeted by the patent
WO2006087520	BP Exploration Operating Co Ltd	
WO9967587,US6289693	Chart Industries Inc.	
WO9967587,US6289693	Process Systems Int. Inc.	
JP2006015277	Kobe Steel Ltd.	
EP1477761,DE10322406,JP2004340569 CA2465599,US2004251003,US7055588	API Scmidt-Bretten GmbH & Co KG	
CN1482057,CN123143C	Henan Yuguang Gold & Lead Co Ltd.	
JP2003320213	Mitsubishi Kasei Eng.KK	
DE10135714,WO03011850,EP1412345, KR20040018494,AU20023555636, US2004182692,CN1535269, JP2005506968T,CN1250537C	BASF AG	
CN1236730,CN1085187C	UNIV East-China SCI &	

	Eng.	
FR2780772	Packinox	
DE10000288, EP1114975	Renzmann & Gruenewald GmbH	
DE10023684	Gea Canzler GmbH	
DE10133958	Canzler GmbH	
DE19519270	Rainer B	
DE19810186	Renzmann & Gruenewald GmbH	
EP1050570, US6413414	Bechtel Corp.	
US2001006104,JP2001194077	Nippon	
US6736200	Shokubai Co Ltd.	

4.3 Institutes/companies working on the technology

(Provide the list of most important research centers and companies in Table 8)

Table 8. Institutes and companies working on the technology

Institute/Company	Country	Remarks
Alfa Laval	Sweden	
Gea Canzler GmbH	Germany	
CERT	France	
Heatric	UK	
ECN	The Netherlands	
Kobe Steel Ltd	Japan	

5. Stakeholders

5.1 Suppliers and developers

(Provide the list of key suppliers/developers in Table 9)

Table 9. Supplier and developers

Institute/Company	Country	Remarks
Alfa Laval	Sweden	
Gea Canzler GmbH	Germany	
Heatric	UK	
Marston	UK	
Linde	Germany	
Tranter	USA	
Schmidt Bretten	Germany	
Vatherus	Finland	
APV	UK	
Alfa Laval/Packinox	France	
Renzmann & Gruenewald GmbH	Germany	
Kobe Steel Ltd.	Japan	

5.2 End users

(Describe the existing and potential end-users, other than those already listed in Table 2)

Aviation Industry

6. Expert's brief final judgment on the technology

(maximum 5 sentences)

The use of Plate Type Heat Exchangers has grown the last decennia exponential. Compactness and low CAPEX were the key sales drivers. However once you have decided to install a compact it will be forever compact. A way back to conventional Shell & Tube is often very difficult due to space limitations. Heat exchanger type selection must be "right the first time".