5. PRODUCTION TECHNOLOGIES

5.1. Chemistry :

From a chemical point of view, a “urethane” is the ester from a carbamic acid

$$R'{-}NH{-}\underset{\underset{O}{\|}}{C}{-}OR$$

A polyurethane is the repetition of this group in a macro-molecular chain and may be obtained by the polymerization reaction of a polyalcohol (polyol) with a poly-isocyanate

$$n\ HO{-}R{-}OH + n\ OCN{-}R'{-}NCO \rightarrow {-}\ (R{-}O{-}\underset{\underset{O}{\|}}{C}{-}NH{-}R'{-}NH{-}\underset{\underset{O}{\|}}{C}{-}O)_n\ {-}$$

In order to obtain a POLYURETHANE FOAM, this polymerization reaction is combined with an expansion reaction, done

- Either by a chemical process : water is added to the blend, reacting with the isocyanate and generating carbon dioxide gas

$$R - NCO + H_2O \rightarrow R{-}NH_2 + CO_2 \nearrow$$

The amine itself reacts also with another isocyanate molecule to form an urea function which contributes to the overall structure of the polymer :

$$\left[R - NH - \underset{\underset{O}{\|}}{C} - NH - R'\right]_n$$

- or by a physical process, using a low boiling agent which is transformed into its gaseous state under the influence of the temperature rise, developed during the exothermic polymerization reactions.

The main feature of the chemistry of the polyurethane foams - in reality much more complicated than described here above - is the very high reactivity of the isocyanate :

- It can be combined with an infinitely large variety of polyols leading to foams of a different hardness : flexible, supersoft, rigid, semi-rigid.
- It can be combined with whatever quantity of blowing agent leading to a density from 0.007 to 1 (7 to 1,000 kg/m^3)

- high production speed : all the components are mixed together leading in one step to a polymer and a foam. This is a unique process.

- Versatility of production processes : continuous slabstock, double conveyor laminator, moulding and spraying processes.

Depending on the nature of the polyol, flexible polyurethane foams are generally divided in two main families : polyether and polyester :

- Polyether polyol : mainly derived from a blend of propylene oxyde and ethylene oxyde.

$$R - \left[O - (\underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2 - O)_x - (CH_2 - CH_2 - O)_y - H \right]_n$$

- Polyester polyol : as for example condensation polymer derived from di-ethylene glycol and adipic acid.

$$R - \left[O - (\underset{\displaystyle O}{\underset{\|}{C}} - (CH_2)_4 - \underset{\displaystyle O}{\underset{\|}{C}} - O - CH_2 - CH_2 - O - CH_2 - CH_2 - O)_x - H \right]_n$$

Generally, for flexible foams, the nominal functionality, n (number of hydroxyl groups per molecule), is 3 in case of flexible ether foams are 2.5 till 3 in case of flexible ester foams.

5.2. Raw materials :

The raw materials for the production of PU foams are classified in 5 families.

The most important are :

1. Polyol :

- Polyether polyol, based on propylene and/or ethylene oxyde : mainly used for comfort applications.

- Polyester polyol, obtained from the condensation between a polyalcohol (as ethylene glycol) and an organic acid (as adipic acid)

2. Isocyanate :

- Toluene diisocyanate (TDI) : 80/20 or 65/35 (ratio of isomer 2.4 and 2.6) : mainly used for flexible foams.
- Methylene diphenyl diisocyanate (MDI) : used for several applications, including rigid foams.

- Isophoron diisocyanate (IPDI) : used for several light UV stable PU products. Other aliphatic isocyanates may be used.

3. Water :

- Water is the chemical blowing agent (reaction with isocyanate to form carbon dioxyde gas).

4. Fixed additives :

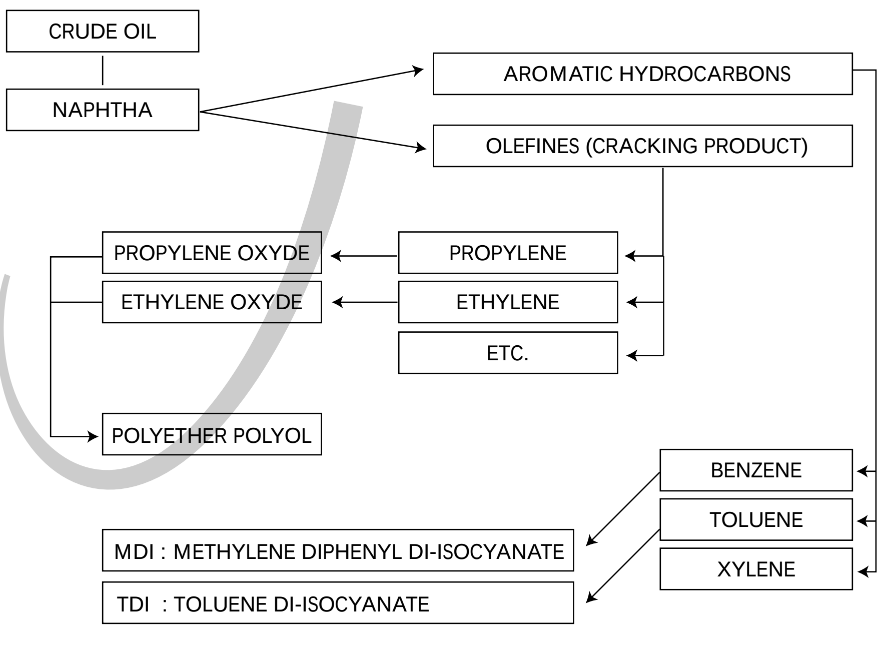
- Catalysts based on amines and organometal derivates.

- Stabilizers based on silicones or non silicones.

5. Optional additives :

- Physical blowing agents
- Fire retardants
- Anti-oxydants
- Colorants
- Crosslinkers
- etc...

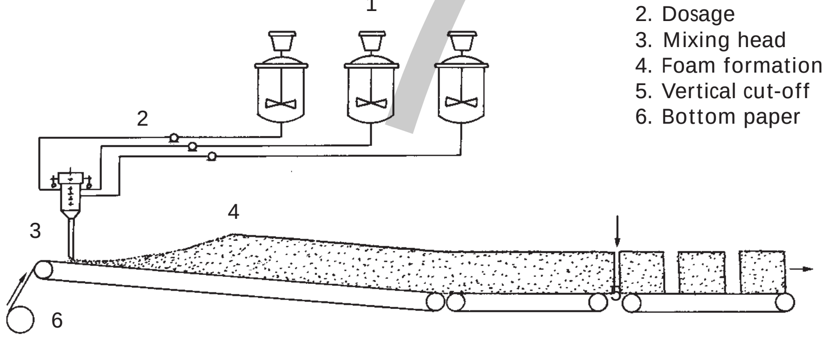
5.3. Raw materials chart from crude oil to Polyol and Isocyanate :



5.4. Continuous slabstock foaming technologies :

5.4.1. Inclined Conveyor.

The emulsion resulting from vigorous mixing of the raw materials is poured onto a rolling conveyor with vertical variable walls.
After a few seconds, a cream is formed, the volume expands and the foam reaches in about one to three minutes its maximum height.
Polyether and polyester polyurethane foams may be produced by this technology.
By variation of the formulations, a wide range of qualities may be obtained.



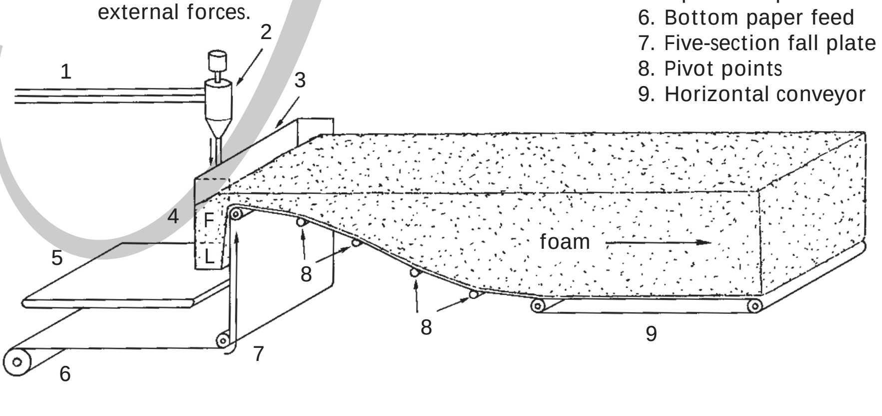
1. Raw materials
2. Dosage
3. Mixing head
4. Foam formation
5. Vertical cut-off
6. Bottom paper

The production of square block shape is a key issue in the slabstock process. By free rise foaming, one obtains blocks with “round tops”, like a bread, due to the mechanical resistance of the side walls. Square blocks are obtained by pulling the foam with a foil on the sides or by pressing the top with a plate.

5.4.2. Downwards foaming

This process is similar but the emulsion “falls” down. By this process, one obtains square blocks without external forces.

1. Raw materials
2. Mixing head
3. Trough
4. F-foam - L-liquid
5. Operator’s platform
6. Bottom paper feed
7. Five-section fall plate
8. Pivot points
9. Horizontal conveyor



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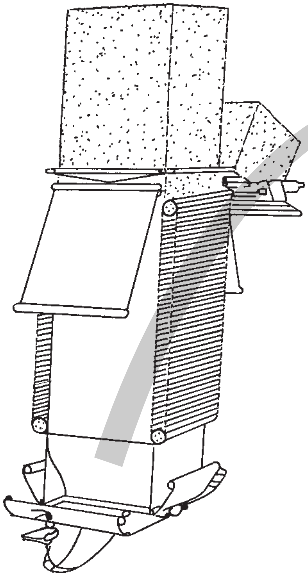
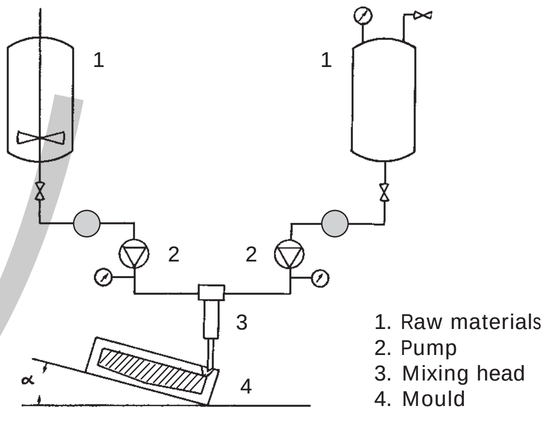
5.4.3. Vertical Foaming.

By this process,
one obtains also square blocks.



5.5. Discontinuous (Moulding) :

Here, the emulsion is poured into a closed or open mould and the foam is formed. This discontinuous process allows to obtain in one step, finished cushions. The process, in terms of “volume” is slower than the slabstock, but avoids the cutting scrap.



R.I.M. (Reaction Injection Moulding) is similar. The raw materials are injected in a closed mould in order to obtain finished pieces of higher density (steering wheel, computer housing, ...).

The moulding technology allows to place an insert in the mould before foaming in order to reinforce the structure of the finished piece.

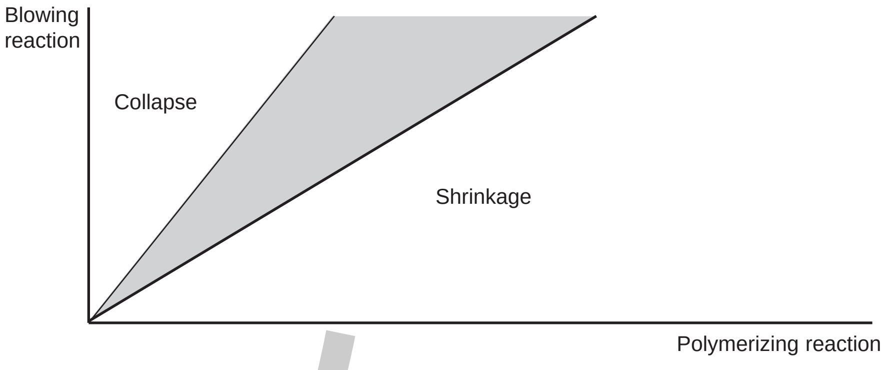
5.6. Foaming : Critical curve (process) :

Foaming remains an “art” : it combines two simultaneous reactions in 5 steps.
The two reactions are the polymerization reaction and blowing reaction.

The five steps are :

* Mixing the liquid raw materials
* Nucleation start
* Start of the reaction
* Stop the reaction (end of rise) while the cells are blowing
* Curing : to finish the polymerization and allowing the hot blocks to cool down

The ratio between the blowing reaction rate and the polymerization reaction rate is the key process parameter : when the first is fast, the foam “explodes” and collapses. When the second is too fast, the blowing is retarded, the foam remains closed and shrinks during cooling. This is illustrated by the “Foaming Critical Curve” : only an appropriate ratio (specific for each foam type) will lead to an appropriate foam.



5.7. Comparison Ether <-> Ester PU foams :

1. Typical advantages ester vs ether :

* Cell structure homogenity / cell count control
* Mechanical properties (hardness / mechanical strength)
* Flame bonding adhesion
* Thermal and HF welding / Thermoforming
* Resistance to photo-oxidative UV ageing (degradation /discolouration).
* Acoustical absorption (lower air permeability)
* Inherent fire resistance
* Resistance to organic solvents (swelling)
* Shock absorption (higher hysteresis)

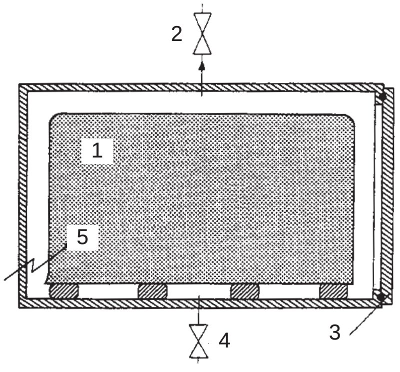
2. Typical disadvantages ester vs ether :

* Price : raw materials and block size = (block yield)
* Humid ageing (hydrolysis)
* Clickability (unless non-clickable applications !)
* Fogging (unless treated ester polyols)
* Smell (unless selection lower odour amine catalysts)
* Comfort properties

3. Air Permeability :

Mostly lower in case of ester -> advantage or disadvantage, depending on applications.

5.8. Reticulation :



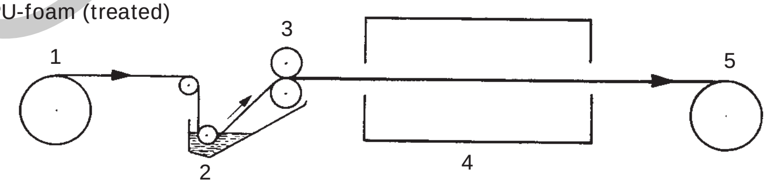
The flexible foams obtained from slab-stock production partially contain closed cells.
By a thermal process - explosion of oxygen-hydrogen in a closed reactor - all the residual cell membranes are melted and a completely open cellular network is obtained.
In principle, all types of flexible foams can be reticulated.

1. Foam
2. Vacuum line
3. Reactor door
4. H_2 and O_2 inlet
5. Ignition plug

5.9. Impregnation :

The impregnation consists in dipping the foam into a bath, squeezing and drying it afterwards in an oven.
Following the nature of the chemicals used for the impregnation, specific new properties are conferred to the foam : flame resistance, HF welding, self-supporting.

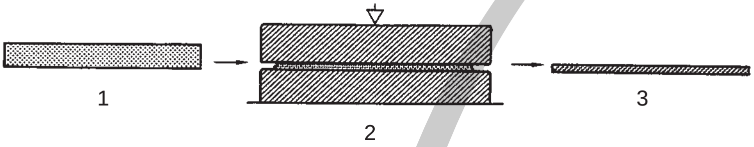
1. PU-foam (non treated)
2. Impregnation bath
3. Nip-rollers
4. Oven
5. PU-foam (treated)



5.10. Densification :

By compression and heating the foam up to a permanent deformation, new cellular materials with a higher density and mechanical properties are obtained.
All types of flexible foams can be densified by this process.

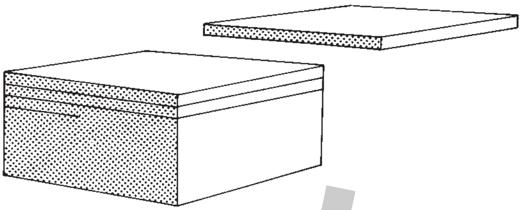
Densification may be alternatively limited to the surface of the foam, leading to a skin formation on one or both sides.



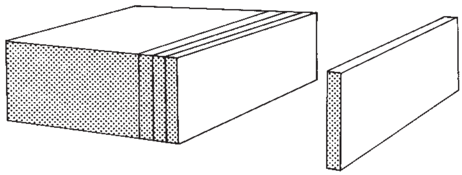
1. Foam sheet before densification
2. Heat press
3. Foam sheet after densification

5.11. Cutting technologies :

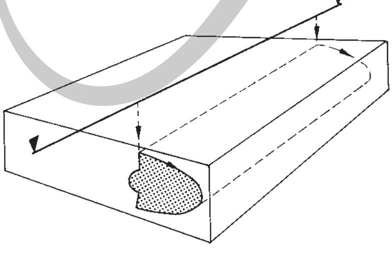
HORIZONTAL SPLITTING



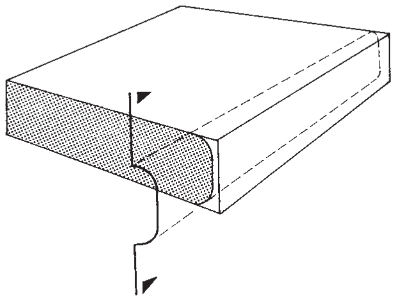
VERTICAL SPLITTING



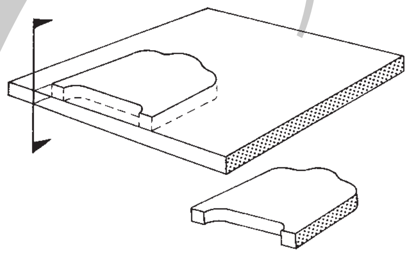
CONTOUR CUTTING



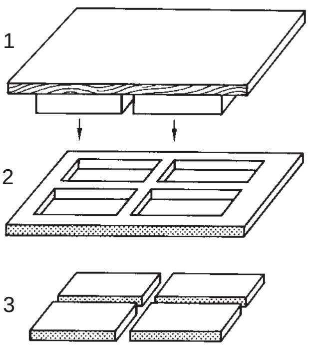
RADIUS CUTTING



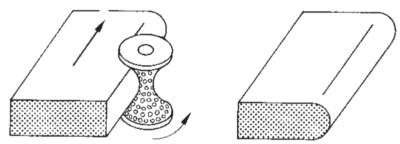
MODEL CUTTING



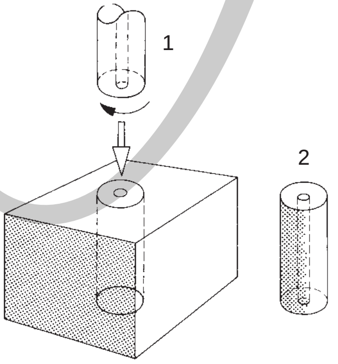
DIE CUTTING



MILLING

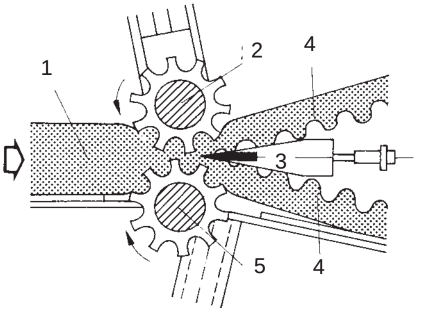


BORING



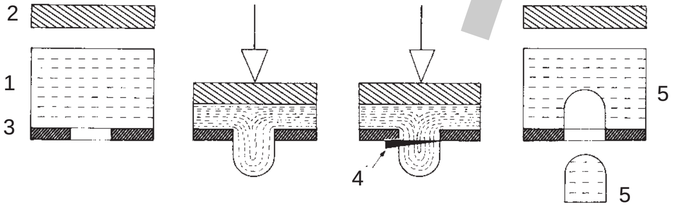
1. Boring tool
2. Finished piece

DEFORMATION CUTTING CONTINUOUS



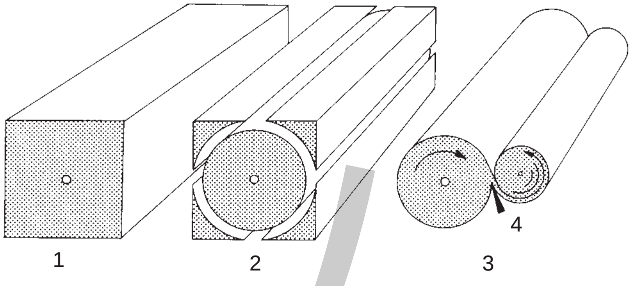
1. Foam sheet
2. Deformation rollers
3. Knife
4. Finished sheets

DEFORMATION CUTTING DISCONTINUOUS



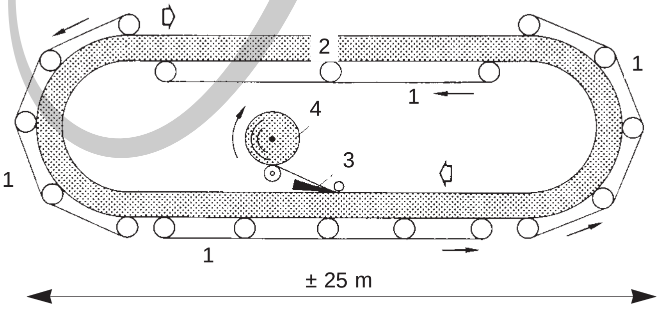
1. Foam
2. Press
3. Deformation tool
4. Knife
5. Finished piece after deformation cutting

PEELING



1. Block
2. Pre-cutting
3. Peeling
4. Knife

ROLL CUTTING

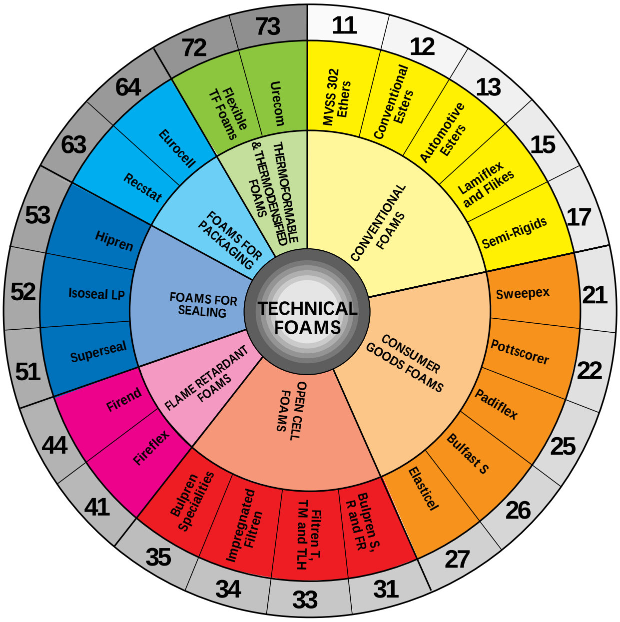


1. Belt
2. Foam
3. Knife
4. Foam roll after cutting

5.12. Conversion table :

		UNIT	SYMBOL	CONVERSION
Length		METER	m	× 3.28084 = ft × 39.3701 = in
		Foot	ft	× 0.3048 = m × 12 = in
		Inch	in	× 0.0254 = m × 0.08333 = ft
Mass		KILOGRAM	kg	× 2.2046 = lb
		Pound	lb	× 0.45359 = kg
Force, weight		NEWTON (= kg.m/sec^2)	N	× 0.10197 = kgf × 0.22481 = lbf
		Kilogramforce	kgf	× 9.80665 = N × 2.20462 = lbf
		Poundforce	lbf	× 4.44822 = N × 0.45359 = kgf
Temperature		Degree Celsius	°C	°F = 9/5 °C + 32
		Degree Fahrenheit	°F	°C = 5/9 (°F − 32)
Volume		Cubic meter	m^3	× 423.789 = bd ft
		Board foot	bd ft	× 0.00236 = m^3
Density	Weight per unit of volume	KILOGRAM PER CUBIC METER	kg/m^3	× 0.06243 = lb/cu ft
		Pound per cubic foot	lb/cu ft	× 16.0185 = kg/m^3
Speed	Displacement per unit of time	Centimeter per minute	cm/min	× 0.03281 = ft/min
		Foot per minute	ft/min	× 30,48 = cm/min
Flow	Volume per unit of time	Cubic meter per hour	m^3/h	× 35.3147 = cu ft/hr
		Cubic foot per hour	cu ft/hr	× 0.02832 = m^3/h
—	Force per unit of length	Newton per linear centimeter	N/cm	× 0.571015 = pli
		Pound per linear inch	pli (lbf/in)	× 1.75127 = N/cm
Pressure, Tension	Force per unit of surface	PASCAL (= Newton per square meter)	Pa	× 0.001 = kPa
		KiloPascal	kPa	× 0.14504 = psi × 0.01020 = kgf/cm^2 × 4.01463 = in wg
		Pound per square inch	psi (lbf/in^2)	× 6.89476 = kPa × 0.07031 = kgf/cm^2 × 27.6807 = in wg
		Kilo per square centimeter	kgf/cm^2	× 98.0665 = kPa × 14.22334 = psi × 393.712 = in wg
		Inch of water gauge	in wg	× 0.24909 = kPa × 0.03613 = psi × 0.00254 = kgf/cm^2

Capital letters = International Standard Units



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