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Another vision of the 40 Inventive Principles with Applications in Chemical Engineering

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Since the first article of (Domb, 1997), with the list of 40 principles with technical examples for an explanation of the 39 parameters, some authors give examples of the principles in various domains. Initially, the Contradiction Matrix had been built to solve technical problems. Recent TRIZ studies, has extended the application of this Matrix into non technical domains : Marketing, sales and Advertising (Retseptor,2005), Finance (Dourson, 2004), Education (Marsh et al, 2004), Quality Management (Reseptor, 2003)...

Nowadays, Chemical Engineering has to face new contexts for example : the gradually falling of hydrocarbon reserves, relocation (for European Countries)... Moreover new domains of application emerge, like nano-micro technologies and biotechnologies, and others have a strong need of our knowledge : Energy for example. All this tendencies and demands accelerate the need to innovate in Chemical Engineering. Basing on current knowledge, it will have to innovate : technically, technologically, and perhaps in the way to theoretically approach problems for example in nano-micro technologies. In this context of innovation in chemical engineering, some people have understand the TRIZ contributions (Poppe, 2002), (Hipple 2005 a, b, c).

In this article, authors try to analogise the TRIZ inventive 40 principles with examples in the Chemical Engineering domain with another vision than the one proposed by (Hipple 2005 d).

1 Segmentation

A Divide an object into independent parts

- Before to react or to be dissolved, a solid phase is fragmented in order to increase its specific area.
- Segmentation of reactive zone in a vertical reactor to avoid attrition in the catalytic bed.

B Make an object easy to disassemble

- Make a heat exchanger with dismantled plate to facilitate the cleaning.
- In a reactor, the reactive zone can be dismantled to easily change the catalyst when it becomes inactive.

C Increase the degree of fragmentation or segmentation

- In process simulation, local adaptive grid methods allow to refine grid near boundary or phenomenon location.

D Transition to micro-level

- Reducing apparatus size with the micro and nano technologies : micro-reactor, micro heat exchanger.

2 Taking out

A **Separate an interfering part or property from an object, or single out the only necessary part (or property of an object)**

- In a crusher, it is difficult to produce solid particles with an uniform size, the following riddling step eliminates undesirable particles.
- In chemical engineering some products need to have high purity (like in fine chemistry, pharmaceutical industry...), consequently the none desirable sub product must be removed. A lot of techniques can be applied : distillation, solvent extraction, membrane ...

3 Local Quality

A **Change an object's structure from uniform to non uniform, change the external environment (or external influence) from uniform to non uniform**

- Use gradient (temperature, pressure, concentration) instead of constant values : multiple effects evaporator (pressure gradient).

B **Make each part of an object function in conditions most suitable for its operation**

- Several feeding position in a distillation column.

C **Make each part of an object fulfill a different and useful function**

- The two extremities of a tensio-active molecule have opposite properties : one is hydrophilic, the other lipophilic.

4 Asymmetry

A **Change the shape of an object from symmetrical to asymmetrical**

- To improve mixing, use asymmetrical tank or asymmetric blade in a symmetric tank.

B **If an object is asymmetrical, increase its degree of asymmetry**

- Deformation of wall shape design in tubes (corrugated surface) in order to obtain hydrodynamic conditions which enhance transfer. The asymmetry of corrugations are increased by changing geometrical characteristics.
- An electrical furnace has electrodes asymmetrically placed permitting the continuous loading of ore and discharge of molten metal.

5 Merging

A **Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations**

- Bundle of tubes in a heat exchanger in order to increase transfer and decrease the size.
- Stirring rod with several identical blades.

B **Make operations contiguous or parallel : bring them together in time**

- It is the goal in process intensification for example reactive distillation.

6 Universality

A **Make a part or object perform multiple functions : eliminate the need of other parts**

- Process Intensification : make several operations in the same apparatus instead of one by apparatus : reactive distillation (reaction and separation in the same column instead of a reactor followed by a distillation column).

- In a crusher with several cylinders, the cylinders turn for grinding and simultaneously they are cooling to avoid overheating (of cylinders and product).

7 'Nested doll'

- A Place one object inside another : place each object, in turn, inside the other**
- Modular approaches in software development for chemical engineering simulation.
- B Make one part pass through a cavity in the other**
- Gas injector in a gas liquid column : the gas passes through holes of the distributor.
 - Heat exchanger principle : both cold stream and hot stream pass through tubes (one inside the other outside) to exchange heat with the other stream.

8 Anti-Weight

- A To compensate for the weight of an object, merge it with other objects that provide lift**
- Use of a foaming agent to bring to the surface particles suspended in a liquid in order to remove them. Inversely, add a coagulating agent to agglomerate suspended particles to create heavier ones for settling.
- B To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces)**
- A solid is put in suspension by a liquid or a gas stream : air lift (gas, liquid), fluidization (gas) principle.

9 Preliminary anti action

- A If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects**
- In reactor, for some chemical reactions high temperature can have a beneficial effect with yield increase. On the opposite side, too high temperature caused the reactor to run out of control (or favored sub product formation). To avoid this harmful effect, the left over energy is removed with a cooling system.
- B Create beforehand stresses in an object that will oppose known undesirable working stresses later on**
- Prepare a system with an inhibitive species for avoiding corrosion (for example).

10 Preliminary action

- A Perform, before it is needed, the required change of an object (either fully or partially)**
- Preheating of stream before inlet in a unit operation (reactor, separator...).
 - Sow a solution with crystals before crystallization.
 - In ink fabrication, some ink qualities necessitate to break up clusters (agglomerates) in a less energy consuming pre-crusher before to put it in the final crusher to give the characteristics desired.
- B Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery**
- Scheduling of multi product production.

11 Beforehand cushioning

A Prepare emergency means beforehand to compensate the relatively low reliability of an object

- In a heat conducting system with salts, the pipe must be pre heated to avoid crystallization.
- Put an emergency stop system on a process.

12 Equipotentiality

A In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field)

- Work under operating conditions without gradients : isotherm, isobar...

13 Inversion/'The other way round'

A Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it)

- In water desalination, to produce pure water the common process is to use evaporation. Nevertheless, one process consists in freezing the sea water to create pure water ice-crystals.

B Make movable parts (or the external environment) fixed, and fixed parts movable

- Couette viscometer : viscometer with two coaxial cylinders. There are two operating modes : one of the cylinders is moving at constant speed and the viscous couple is measured, conversely, one of the cylinders can move under the action of a couple and the speed is measured. The internal or external cylinder can turn.

C Turn the object (or process) 'upside down'

- Inverted Batch distillation : in the conventional batch distillation column, the feed is charged to the still, while products are withdrawn sequentially from the top, according to their relative volatilities. In the inverted batch distillation, the feed is charged at the top while the product are withdrawn from the bottom of the column.

14 Spheroidality - Curvature

A Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones ; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures

- In a LPCVD reactor (Low Pressure Chemical Vapor Deposition) change a vertical (or horizontal) reactor by an annular one in order to decrease stagnant zone and progressive reagent exhaustion.

B Use rollers, balls, spirals, domes

- Calandrage : film, sheet, plate fabrication by lamination of a thermoplastic matter between several parallel cylinder (the cylinders flatten the matter).
- Crusher with balls or tri-cylinders crusher.

C Go from linear to rotary motion, use centrifugal forces

- Put cyclone at hydrocarbon decanter inlet (in the step of exploitation oilfield) for eliminating solid particle before decantation.
- Principe of rotary furnace.

15 Dynamics

- A Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition**
 - Different reflux policies in batch distillation : variable reflux, reflux by steps.
- B Divide an object into parts capable of movement relative to each other**
 - Tank with a stirring rod.
- C If an object (or process) is rigid or inflexible, make it movable or adaptive**
 - An adapting (moving) grid during the simulation evolving : for example in population balance the distribution size evolves under aggregation and break up.

16 Partial or excessive actions

- A If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve**
 -

17 Another dimension

- A If an object moves in a straight line, move it in two – or three-dimensional space**
 - In some cases, use column internals (packing) to distribute liquid in the whole column section instead of a flowing film on the wall.
- B Use a multi-story arrangement of objects instead of a single-story arrangement**
 - Heat exchanger with a bundle of tubes (instead of one tube).
 - Put in parallel several operations (apparatus) to increase production : electrolyze cells in parallel for ozone production.
- C Tilt or re-orient the object, lay it on its side**
 - Evaporator with tilted tubes.
 - Turbine with tilted blades : more moderate shear stress. More interesting capacity of circulation for the setting in suspension of a solid.
- D Use 'another side' of a given area**
 - Use the outside wall of a reactor to bring or evacuate heat

18 Mechanical Vibration

- A Cause an object to oscillate or vibrate**
 - Oscillating or vibrating sieve.
- B Increase its frequency (even up to the ultrasonic)**
 - Powder distributor, vibrating screening machine.
 - Use of ultrasound for precipitation to obtain smaller particle and to control size distribution.
- C Use an object's resonant frequency**
 - Characterization of solid by nuclear magnetic resonance.
- D Use piezoelectric vibrators instead of mechanical ones**
 - Some rheometers increase their frequency scale by the use of a rotating piezoelectric vibrator : it allows to measure the viscoelastic characteristic of fluid.
- E Use combined ultrasonic and electromagnetic field oscillations**
 - Mixing of alloys in an induction furnace.

19 Periodic Action

A Instead of continuous action, use periodic or pulsating actions

- In a liquid-liquid extraction column, the circulation of fluid is moved by a pulsating piston.

B If an action is already periodic, change the periodic magnitude or frequency

- Frequency change for a pulsating piston in a liquid-liquid column extraction.
- In a pilot distillation column, the reflux is ensured by a pneumatic system which directs liquid (at the top) to the column or to the distillate. The time ratio between the two positions gives the reflux rate. Consequently, the reflux (important operating parameter) frequency (between the two positions) is changed with the modification of times.

C Use pauses between impulses to perform a different action

- In a batch production, the periods of apparatus inactivity are used for cleaning or to realize a new production.

20 Continuity of useful action

A Carry on work continuously ; make all parts of an object work at full load, all the time

- Feed continuously unit operation (reactor, distillation column) instead of batch operating conditions.
- In a process run the bottleneck operations continuously.

B Eliminate all idle or intermittent actions or work

-

21 Skipping/Rushing through/Hurrying

A Conduct process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed

- Use catalyst to accelerate chemical reaction to avoid sub product formation (for example).
- In plastic sheet production, sheets are cut with a high temperature system. The cutting operation has to be faster than the heat propagation in the plastic, to avoid to deform it.
- In some numerical methods, the convergence speed is accelerated in order to decrease the computation time.

22 'Blessing in disguise' or 'Turn lemons into lemonade/ Convert harm into benefit

A Use harmful factors (particularly, harmful effects of the environment .or surrounding) to achieve a positive effect

- Recycle waste product from a process as raw material for another : use waste heat to produce water vapor, use household refuses to produce heat.

B Eliminate the primary harmful action by adding it to another harmful action to resolve the problem

-

C Amplify a harmful factor to such a degree that it is no longer harmful

- In its production, the sea salt is cleaning with water to purify it. The principal drawback is that the sea salt is dissolved in water. The cleaning water is saturated with sea salt to dissolve only impurities.

- 23 Feedback**
- A Introduce feedback (referring back, cross-checking) to improve a process or action**
- Process regulation.
- B If a feedback is already used, change its magnitude or influence**
- Modify the temperature order in a temperature regulator.
- 24 Intermediary/Mediator**
- A Use an intermediary carrier article or intermediary process**
- Use heat conducting fluid to drive heat from its production to the unit operation (heat use).
- B Merge one object temporarily with another (which can be easily removed)**
- Use solvent separation technique to extract one constituent of a mixture. Then the constituent and the solvent are separated to have pure constituent on one side and recycled solvent in the other side.
- 25 Self service**
- A Make an object serve itself by performing auxiliary helpful functions**
- Use the heat produced by a chemical reaction to accelerate the kinetic rate of the same reaction.
- B Use waste resources, energy, or substances**
- Principle of recycling in Chemical Engineering process.
 - Heat recovery in process.
 - Use mud of water purification station to create compost.
- 26 Copying**
- A Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies**
- Use of virtual reality in process instead of real tests : in operator formation, changing of operating conditions for example.
- B Replace an object, or process with optical copies**
- Use of pictures (and picture treatment) to measure particles dimension (to determine particle distribution) or to measure flow characteristics : PIV technique...
- C If visible optical copies are already used, move to infrared or ultraviolet copies**
- Use infrared picture to detect heat source or to measure temperatures : ITER project.
- 27 Cheap short-living objects**
- A Replace an expensive object with a multiple of inexpensive objects, comprising certain quality (such as service life, for instance)**
-
- 28 Mechanics substitution**
- A Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means**
- Ultrasound to create emulsion instead of mechanical mixing.
- B Use electric, magnetic and electromagnetic fields to interact with the object**
- Induction heating with a variable magnetic field to heat a mixture.

- C Change from static to movable fields, from unstructured fields to those having structure**
 - Potential field with ions migration in an electrochemical cell.
 - D Use fields in conjunction with field-activated (e.g. ferromagnetic) particles**
 - Magnetic sorting : a magnetic field is used to separate in a solid mixture, the none magnetic constituent from magnetic ones (like iron, cobalt...)
- 29 Pneumatics and hydraulics**
- A Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive)**
 - In energy production use fuel cell (liquid and gas) instead of uranium ore.
- 30 Flexible shells and thin films**
- A Use flexible shells and thin films instead of three dimensional structures**
 - Separation by reverse osmosis.
 - Pervaporation separation.
 - B Isolate the object from the external environment using flexible shells and thin films**
 - To avoid corrosion, metals are protected with thin films.
- 31 Porous materials**
- A Make an object porous or add porous elements (inserts, coating, etc.)**
 - To increase active surface of a solid catalyst, the particles are became porous.
 - B If an object is already porous, use the pores to introduce a useful substance or function**
 - Hydrogen storage with active carbon or carbon nanotubes or nanofibres (hydrogen is adsorbed on the solid surface).
 - In distillation, internals of column serve for liquid distribution to improve transfer. In reactive distillation a catalyst is put down internals (catalytic packing).
- 32 Color changes**
- A Change the color of an object or its external environment**
 - To take picture with a camera which only detect fluorescent light, a coloring (rhodamine) is added to the mixture to measure temperature (fluorescent intensity depends on temperature).
 - B Change the transparency of an object or its external environment**
 - Transparent tank wall to make easier the camera shooting during the Particles Image Velocity measurement.
 - C In order to improve observability of things that are difficult to see, use colored additives or luminescent elements**
 - Riboflavin, aluminum, titanium dioxide are colored additives added to pharmaceutical products or foodstuffs.
 - D Atoms which can be spotted**
 - Use of a radioactive substance tracer to determine, resident time distribution.

- 33 Homogeneity**
- A Make objects interacting with a given object of the same material (or material with identical properties)**
- When a vibrating rod transmits ultrasonic waves to molten steel, the rods loses some of its substance. To prevent pollution, the rod is made of the same substance as the molten steel.
 - To melt frozen oxygen, introduce oxygen vapor.
- 34 Discarding and recovering**
- A Make portions of an object that have fulfilled their functions go away – discard by dissolving, evaporating, etc.) or modify these directly during operation**
- In liquid-liquid extraction : solvent regeneration.
- B Conversely, restore consumable parts of an object directly in operation**
- Absorbent regeneration by using infrared (air treatment).
- 35 Parameter changes**
- A Change an object's physical state (e.g. to a gas, liquid, solid)**
- Crystallize a component of a mixture to facilitate its separation.
 - To extract a constituent, of a liquid mixture, under gas state.
- B Change the concentration or consistency**
- To struggle against corrosion, decrease the concentration of dissolved oxygen in water (its harmful action is proportional to its concentration)
- C Change the degree of flexibility**
-
- D Change température (pressure...)**
- Heating feed inlets of an apparatus.
 - Change the operating pressure level to facilitate the separation of a multi-constituent mixture.
- 36 Phase transitions**
- A Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat etc.)**
- Energy exchanged during evaporation and condensation : heat pump.
- 37 Thermal expansion**
- A Use thermal expansion (or contraction) of materials**
- Plastic injection or injection blowing (or blowing extruder) then the plastic takes the mould form before to be cooled.
- B If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion**
-
- 38 Strong oxidants**
- A Replace common air with oxygen-enriched air**
- Copper or Nickel converters use oxygen like oxidant. The more the air has oxygen, the more the conversion rate is, the less the volume of recycled gas.
- B Replace enriched air with pure oxygen**
- In waste water treatment, pure oxygen or gas enriched with oxygen are used instead of air in order to treat high concentration of carbon organic pollution.

- C Use ionized oxygen**
 - Oxygen is used in ozone production in water treatment (ozonised oxygen production).
- D Replace ozonised (or ionized) oxygen with ozone**
 - Use of ozone for disinfections of drinking water
 - Smell treatment by advanced oxidation by ozonation.

39 Inert atmosphere

- A Replace a normal environment with an inert one**
 - To prevent chemical product explosion (due to oxygen presence), the apparatus are under inert atmosphere (generally nitrogen).
- B Add neutral parts, or inert additives to an object**
 - Evaporation under vacuum : this operating condition enable to evaporate mixture that can be deteriorated at high temperature. Moreover the evaporation rate is increased and the heating pressure is decreased.
 - Distillation is used to separate components but in some cases components interact each other, forming azeotropes which limit the scope of separation. For this reason another component (entrainer) is added to the mixture to enable further separation.

40 Composite materials

- A Change from uniform to composite (multiple) materials**
 - Use of composite material (instead of steel) for high pressure tank, storage and transport of industrial gas, water treatment (corrosion resistance), better longevity against environmental and fluids attacks.

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