The supply system of safe drinking water using nanofiltration

利用纳米过滤技术的安全饮用水供给系统

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Major concerns for drinking water in Japan and developing countries
主要关注日本和发展中国家的饮用水

Stage 阶段	Safety		Taste 味	Country 国家
	Fundamental items, such as microorganisms 基本指标如微生物含量	Micro-pollutants 微污染物		
1	+++	+	+	
2	+++	+++	+	
3	++	+++	+	
4	+	++	++	
5	+	++	+++	Japan 日本

Example of Stage 3
Water quality (micro-pollutants) of tap water in a city in China

阶段3的实例–中国某市自来水水质（微污染物）

Item 项目	Detected/total number 测定数/总数	Concentration, μg/L 浓度mg/L
All targets 总检测目标物	58/830	10.9
Pesticides 杀虫剂	19/399	3.5

Unique detected chemicals (parentheses are concentrations, μg/L)

特殊测定化合物（括号中为浓度，μg/L）

2-(Methylthio)-benzothiazol2-(甲硫基)-苯并噻唑(1.3), Tris(2-chloroethyl) phosphate三(2-氯乙基)磷酸盐 (0.92), 2-Amino-6-nitrotoluene 2-氨基-6-硝基甲苯(0.92), Atrazine 阿特拉津(0.81), 4-Nitroaniline4-硝基苯胺 (0.42), 2-Nitroaniline2-硝基苯胺 (0.32), 2,6-Dichloro-4-nitroaniline 2,6-二氯-4-硝基苯胺 (0.13)

These results show that tap water was polluted by many chemical substances.

这些结果说明自来水被多种化学物质污染。

Countermeasures to obtain high quality drinking water
获得高质量饮用水的对策

Stage 阶段	Improvement of quality of environmental waters 改进环境水质量	Conventional water treatment 传统水处理	Advanced water treatment 高级水处理	Bottled water 瓶装水	On site water treatment "Super-Aqua" 原位水处理 "超级水"
1	Effective有效	Effective有效		Effective有效	
2		Effective有效		Effective有效	Effective有效
3		Effective有效		Effective有效	Effective有效
4		Effective有效	Effective有效	Effective有效	Effective有效
5			Effective有效	Effective有效	Effective有效
Quality 质量	-	Medium - high, but contamination and leakage can occur during distribution 中-高，在传输的过程中会发生污染和渗漏	High, but contamination and leakage can occur during distribution 高，在传输的过程中会发生污染和渗漏	Usually high 通常较高	High 高
Cost 费用	Very high 非常高	Low – medium 低-中 0.18 Yen/L （日元/升）	High 高	Extremely high 相当高 150 Yen/L	Medium 中等 4 Yen/L

Possible problems of the conventional water supply system
传统水供给系统可能存在的问题

Raw water ⟶ | Water treatment facility | ⟶ | Distribution network | ⟶ User

Raw water
未净化的水

Water treatment facility
污水处理厂

Distribution network
传输网

User
用户

Pollution by various substances and microorganisms.

High-tech and big costs are required to produce a safe and good-tasting water that meet drinking water standards.

Both leakage and contamination occur during water distribution.

Users cannot drink raw tap water.

被多种物质及微生物污染

产出符合饮用标准的安全、美味的水需要高科技和高成本

在传输的过程中会发生渗漏和污染

用户不能饮用自来水

Consumption of tap water in Japan
日本自来水的消耗量

洗手
Washing
hands, 6

其他
Others, 2

饮用
Drinking, 1

冲厕
Toilet, 19

Use volume
370L/person/day
in Kitakyushu

在北九州每人每天消耗量370 L

洗澡
Bath, 26

洗衣服
Laundry,
21

烹饪
Cooking,
25

(%)

Because we drink only 2-3 liter a day, the 2-3 liter of water should be safe and good-tasting.因为我们每天只饮用2-3L水，这些水应该安全且美味。
Most citizens do not think that it is wasteful to pay a lot of money for safe and good-tasting water. 大多数的居民认为花较多的钱购买安全且美味的水不是一种浪费。

Price of water products in Japan
日本的水产品价格

Water product 水产品	Price 价格
Tap water 自来水	180Yen/m^3（日元/m3）
Ultra pure water 超纯水	1,000Yen/m^3 （日元/m3）
Bottled water 瓶装水	150,000Yen/m^3（日元/m^3）
Sports drink 运动饮料	200,000Yen/m^3 （日元/m3）
Canned beer 罐装啤酒	550,000Yen/m^3 （日元/m3）

Changes in the way of thinking
转变思想

Until now 迄今

Water suppliers think to provide tap water that meets the quality of WHO or the national standards.

水厂认为提供的自来水的水质满足了世界卫生组织的质量或者国家标准。

But 但是

Since people drink only 2 liters a day, it is enough that the 2 liters should be safe and good-tasting.

既然人们每天只喝2升水，那么保证这2升水的安全和美味就已经足够了。

Therefore 因此

It is not necessary to treat all raw water to meet the water quality standards.

没有必要处理全部未净化的水使其都达到饮用水的标准。

Two liters of tap water is treated just before use to meet the standards.

使用前处理2 L自来水，使其达到饮用标准。

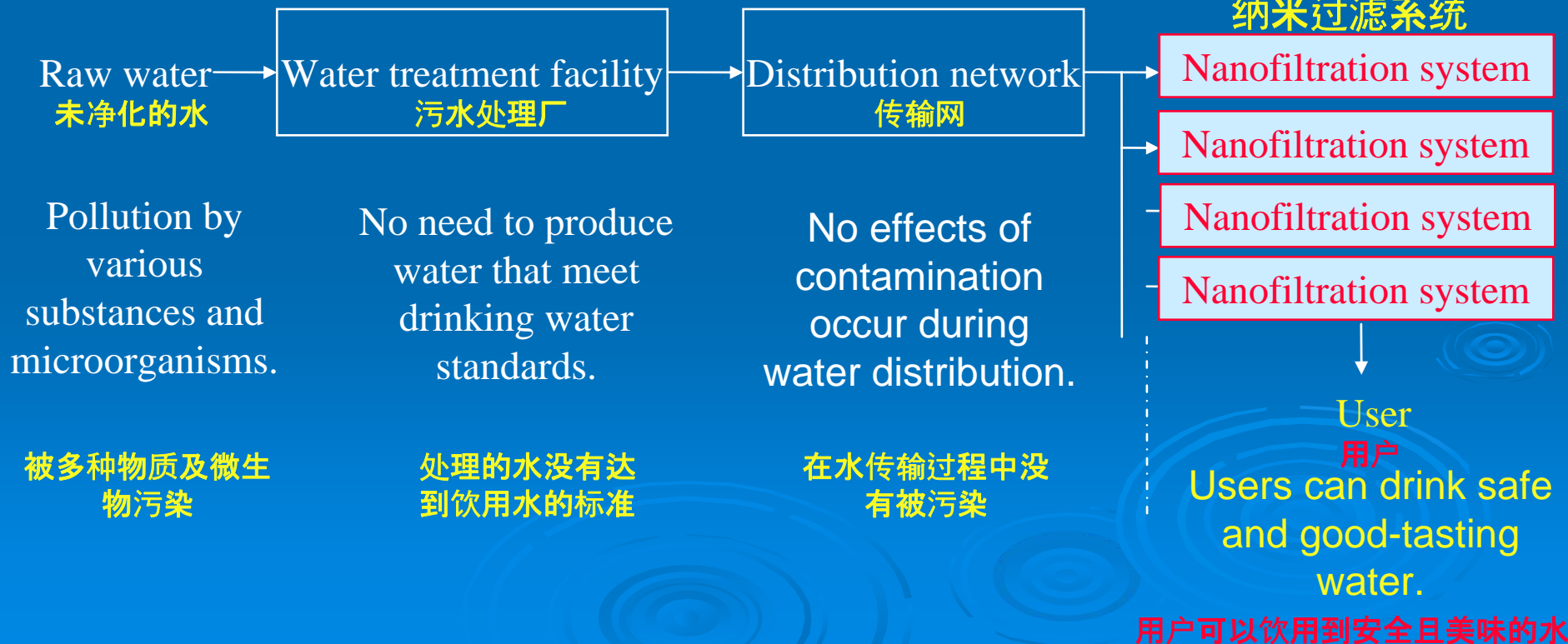# Decentralized water treatment system for drinking water

饮用水分散水处理系统

Because people drink only 2 liter a day,
it is enough that the 2 liter of water is treated.

因为人们每天只喝2L水，那么处理这2 L水就够了。

Super-Aqua

纳米过滤系统

Raw water → Water treatment facility → Distribution network → Nanofiltration system
未净化的水   污水处理厂   传输网   Nanofiltration system

Nanofiltration system

Nanofiltration system

| Pollution by various substances and microorganisms. | No need to produce water that meet drinking water standards. | No effects of contamination occur during water distribution. | |

User
用户
Users can drink safe and good-tasting water.

被多种物质及微生物污染

处理的水没有达到饮用水的标准

在水传输过程中没有被污染

用户可以饮用到安全且美味的水

In the case of Kitakyushu, Japan
以日本北九州市为例

➤ There are 2 water sources in Kitakyushu.
北九州有两个水源。

➤ Since the quality of the raw water from one is very bad, many citizens complained about the quality of tap water even though it meets the national standards.
因为一个水源的水质很差，所以尽管处理的水都达到了国家标准，但是很多市民还是抱怨自来水的水质。

➤ We focused on the fact that people drink only 2 – 3 liters a day.
我们关注的事实是人们每天只喝2-3L水。

➤ We wanted to provide safe and good-tasting water at low cost.
我们希望能够提供安全、价廉而且美味的水。
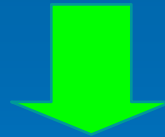
Development of a re-purification system at the end of water supply

在水供给的终端发展一种重复-过滤系统

Target quality of drinking water
饮用水指标质量

Item 项目	Target value 目标值	
Turbidity 浊浊度	Less than 0.1	
Color 色度	Less than 1	
KMnO$_4$ consumption 高锰酸钾消耗量	Less than 1.0	Organic matter & sulfate
TOC 总有机碳	Less than 0.6	
SO$_4^{2-}$ 硫酸根	Less than 10 mg/L	
Total hardness 总硬度	30 – 50 mg/L	Minerals
EC 乳油	200 μS/cm	

The values were decided by using various data about the taste of water.

利用有关水味道的多种数据确定这些数值

How to obtain target quality of drinking water
如何得到引用水的指标质量

➢ To remove substances that cause bad-tasting

   Organic matter, offensive odor substances, SO_4 ion, etc

去除能引起不良味道的物质（有机物、难闻气味的物质和硫酸根离子等）

➢ Not to remove the substances that provide good-taste, such as minerals
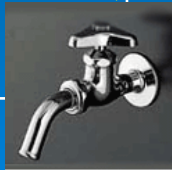
保留能使水具有较好味口感的物质，如矿物质

Treatment system using nanofiltration

利用纳米过滤处理系统

Membranes and their pore size
膜与其孔隙尺寸

Pore size 孔隙尺寸	10^{-8}cm 0.1nm		10^{-7}cm 1nm		10^{-6}cm 10nm		10^{-5}cm 100nm		10^{-4}cm 1μm		10^{-3}cm 10μm
Separation target 分离指标	H_2O	Cl^- Na^+ Ca^{2+}	Glucose 葡萄糖	Humic substance 腐殖质	Virus 病毒	Colloidal particle	胶粒	Oil emulsion 油乳化佐剂	Latex 橡胶	Escherichia coli 大肠埃希氏菌	Staphylococcus 葡萄球菌属

Micro filtration (MF) 微滤

Ultra filtration (UF) 超滤

Nanofiltration (NF) 纳米过滤

Reverse osmosis (RO) 反相渗透

1.5kgf/cm²

Membrane 膜

| Operating pressure, kgf/cm² 运行压力 | 7 | | 3 | | 1 | | | | | | |

Outline of experiments
实验大纲
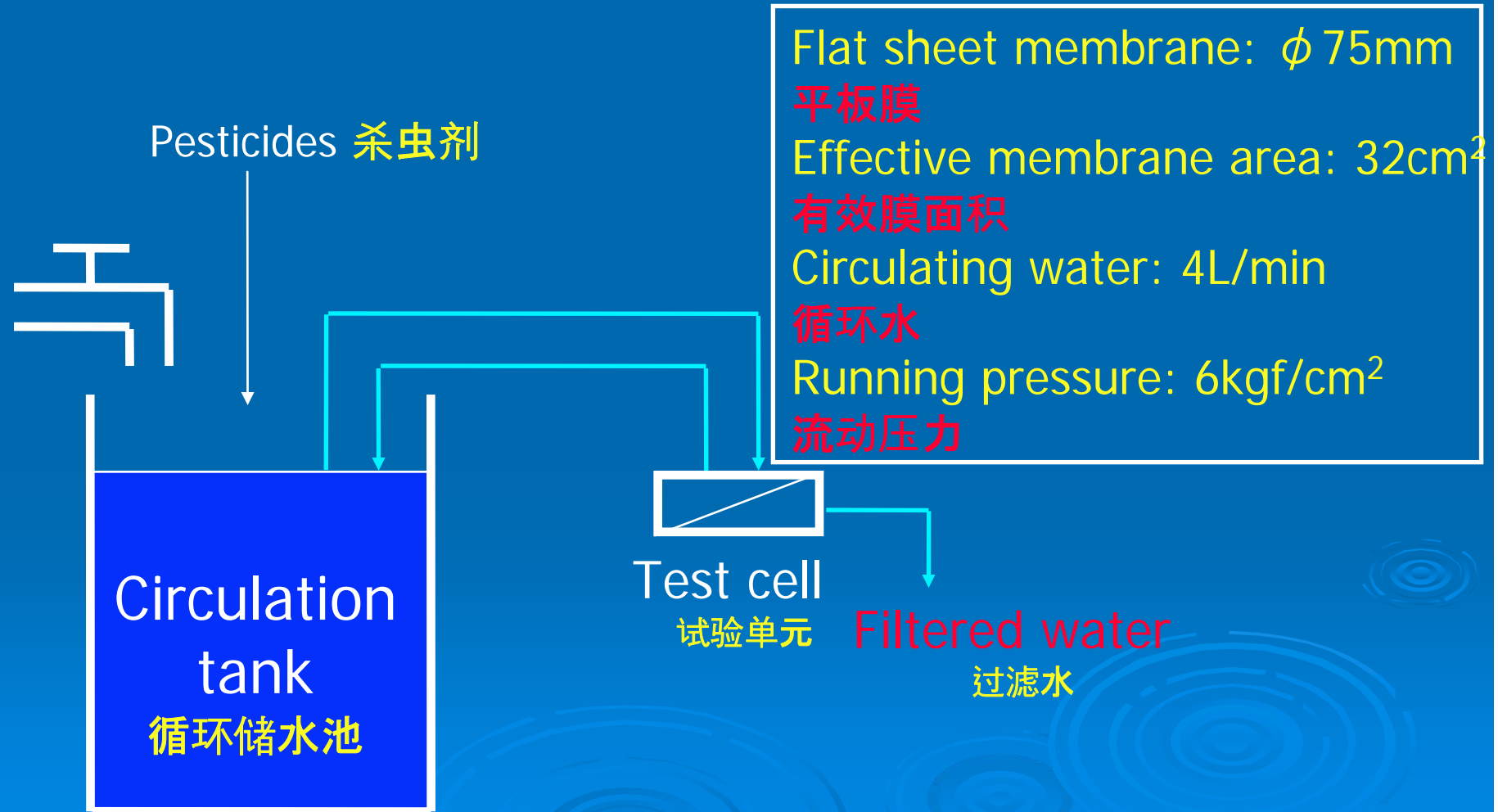
> ### Laboratory testing 实验室试验
>
> - ✓ Membrane selection
>   膜的选择
> - ✓ Removal test of musty odor substances and pesticides
>   霉味物质以及杀虫剂的去除试验
>
> ### Pilot-scale testing 中试
>
> - Effects of pressure on recovery ratio
>   压力对回收率的影响
> - Removal test of musty odor substances and arsenic under continuous operation
>   连续操作条件下，霉味物质及砷的去除试验

Laboratory testing
实验室试验

Pesticides 杀虫剂

Flat sheet membrane: ϕ75mm
平板膜
Effective membrane area: 32cm^2
有效膜面积
Circulating water: 4L/min
循环水
Running pressure: 6kgf/cm^2
流动压力

Circulation
tank
循环储水池

Test cell
试验单元

Filtered water
过滤水

Nanofilters used in the lab testing

实验室试验中用到的纳米过滤器

Membrane 膜	A1	A2	A3	B1	B2	B3
Material 材料	Polymer 聚合体	Cellulose 纤维素	Cellulose 纤维素	Polymer 聚合体	Polymer 聚合体	Cellulose 纤维素
Rejection efficiency for NaCl, % NaCl的拒绝效率	40	30	<10	60	55	85

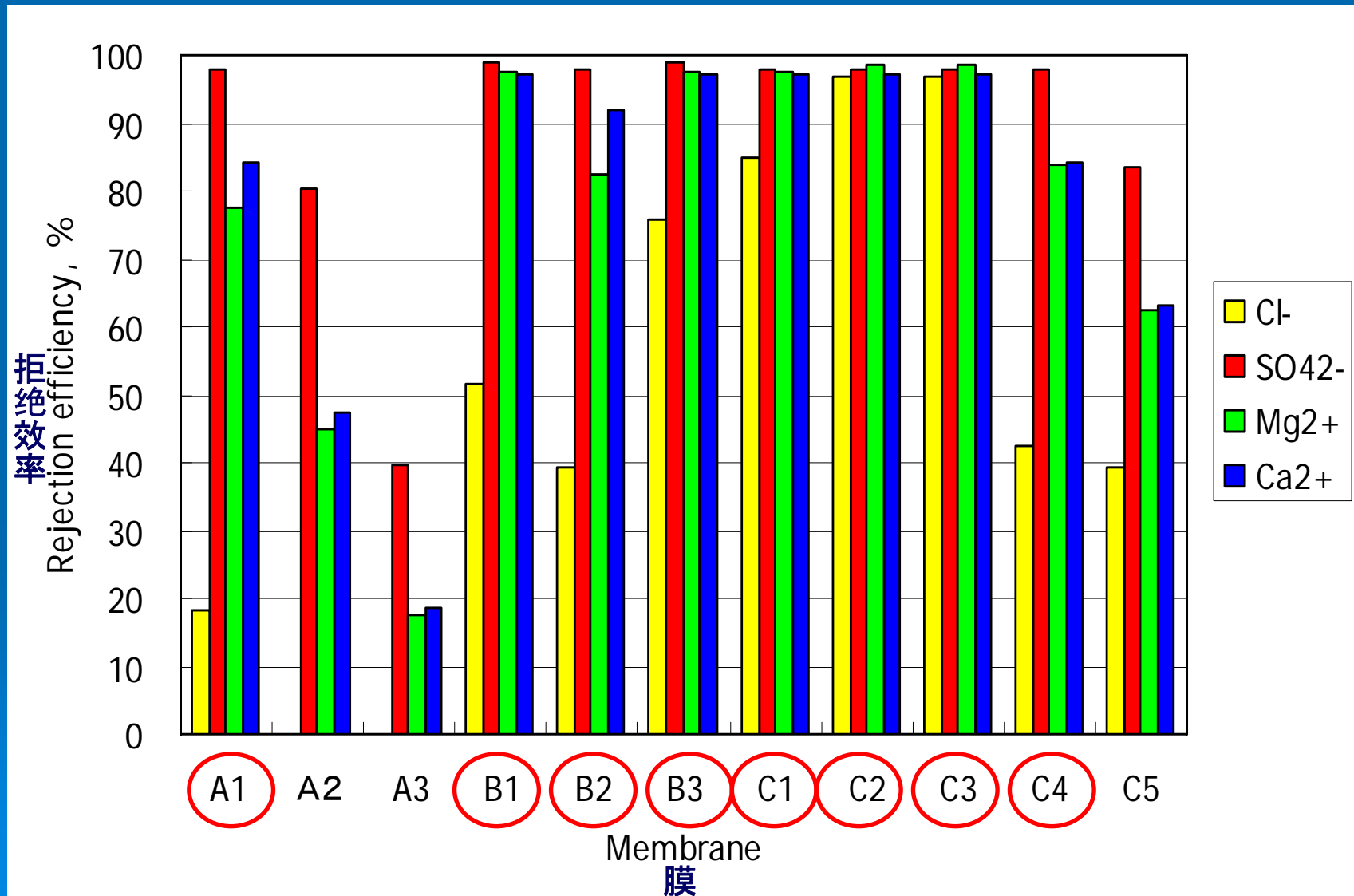| Membrane 膜	C1	C2	C3	C4	C5
Material 材料	Polymer 聚合体	Polymer 聚合体	Polymer 聚合体	Polymer 聚合体	Polymer 聚合体
Rejection efficiency for NaCl, % NaCl的拒绝效率	92	99.5	99.5	60	50

Rejection efficiency of organic matter
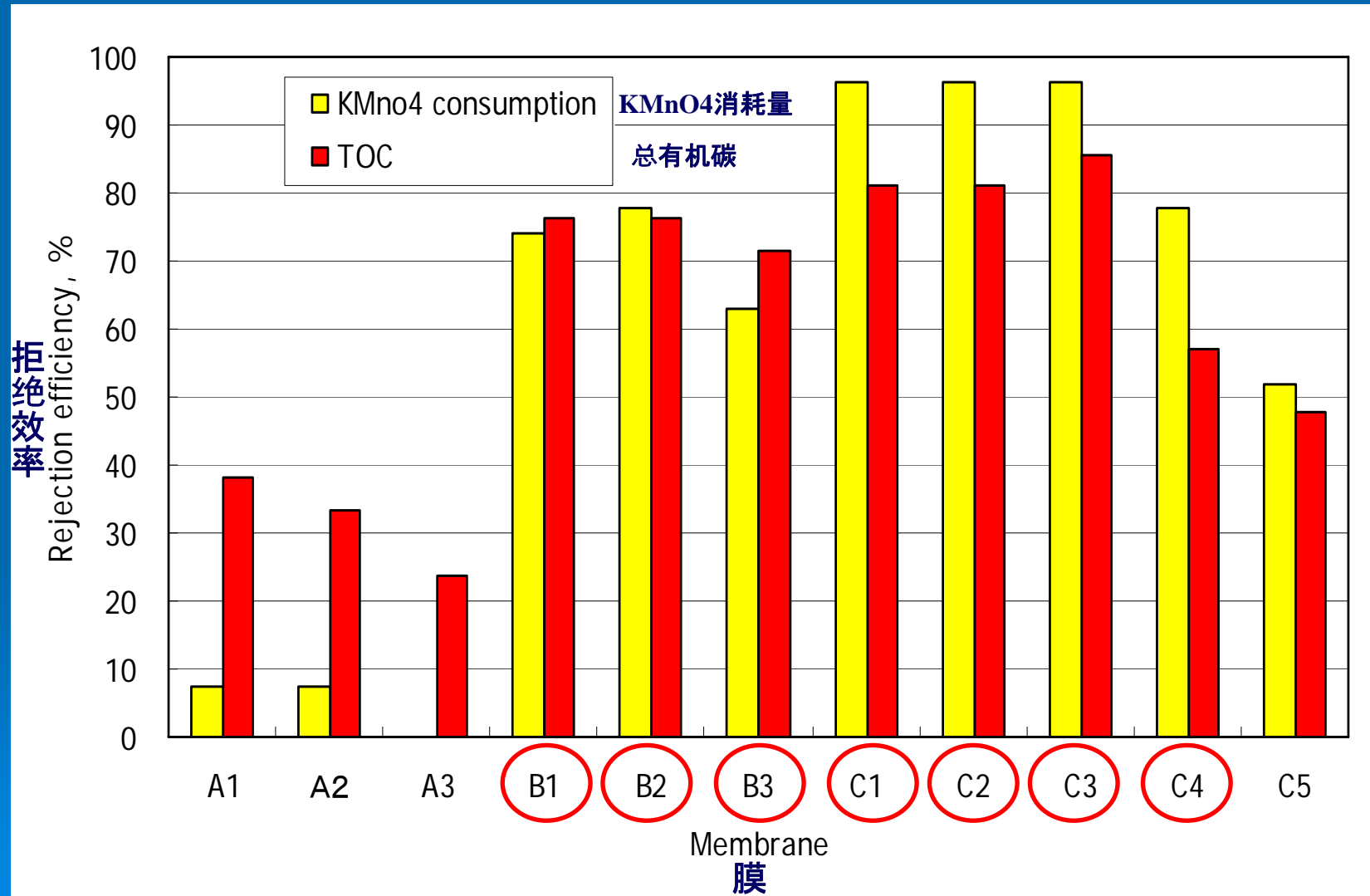
有机物拒绝效率

Rejection efficiency of inorganic ions

无机离子拒绝效率

Final candidates of membrane

膜的最终确定

Item 项目	A1	A2	A3	B1	B2	B3	C1	C2	C3	C4	C5
Rejection efficiency of organic matter 有机物拒绝效率				Good	Good	Good	Good	Good	**Good**	**Good**	
Rejection efficiency of ions 离子拒绝效率	Good			Good	Good	Good	Good	Good	**Good**	**Good**	
Filtration flux 过滤通量		Good	Good	Good	Good				**Good**	**Good**	Good

➢ Membrane filtration flux of A2, A3, B1, B2, C3, C4 and C5 filters were 35L/m^2/h.
过滤器A2、A3、B1、B2、C3、C4 和C5 的膜过滤通量为35 L/m^2/h。

➢ Membrane filtration flux of others were a half of A2, A3, B1, B2, C3, C4 and C5 filters.
其它过滤器的膜过滤通量是A2、A3、B1、B2、C3、C4 和C5 的一半。

From the results of rejection efficiencies of ions and organic matter and membrane filtration flux, we chose C3 and C4 filters.
根据这些离子和有机物的拒绝效率以及膜过滤通量的试验结果，我们选用C3和C4过滤器。

Most suitable membrane for good-tasting water
美味的水适宜的膜

Item项目	Rejection efficiency 拒绝效率, %	
	C3	C4
Total hardness总硬度	100	65
$KMnO_4$ consumption**KMnO4消耗量**	94	75
EC 乳油	99	61
THM潜在有毒物质	89	37
2-MIB **2-**甲基异茨醇	100	89
Geosmin 土腥素	100	100
Pesticides杀虫剂 (10)	100	90

Operating-pressure（工作压力）: $4kgf/cm^2$

C4 satisfies the target water quality.

Pilot-scale testing for the decentralized treatment system
分散处理系统的中试