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Life Cycle Impact Assessment (LCIA) of Potable Water Treatment Process in Malaysia: Comparison Between Dissolved Air Flotation (DAF) and Ultrafiltration (UF) Technology

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Abstract: This Life Cycle Impact Assessment (LCIA) study compares two types of drinking water technologies; Dissolved Air Flotation (DAF) technology and Ultra Filtration technology. The selected plant for this study has both types of technologies in use. Collected data are from the usage of electricity and chemicals used in the water treatment process. The Eco-Indicator 99 was chosen to indicate extent of damage from collected inventories. From the result of impact assessment conducted, it is found that Ultrafiltration technology contributes higher impact to all three categories of damages; damage to environmental quality, damage to human health and damage to source when this technology is compared to DAF technology.

Key word: Dissolved Air Flotation (DAF), Ultrafiltration (UF), Water Treatment Process, Life Cycle Impact Assessment (LCIA)

INTRODUCTION

DAF and Ultrafiltration (UF) technologies are two technologies regarded as new in Malaysian's drinking water treatment process. The DAF technology was said to be in use in Malaysia since early nineties. So far, the use of DAF technology is available only at 11 plants throughout Malaysia including a plant in Kinta, Perak which will be in operation soon. Generally, a water treatment plant that uses DAF technology can be illustrated in Figure 1.1.

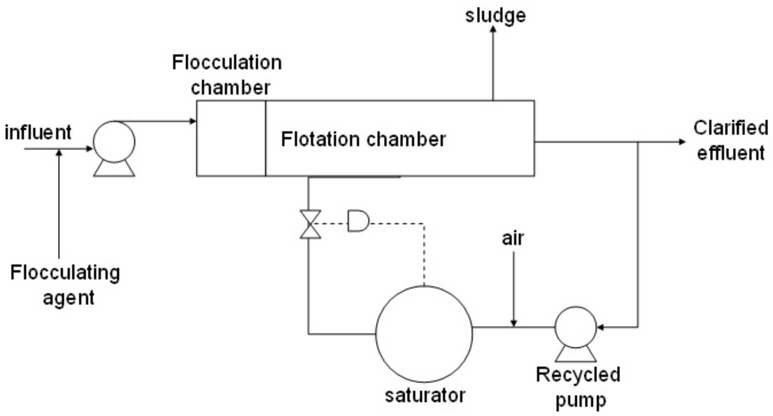

Fig. 1.1: Schematic diagram of water treatment plant with DAF technology (Lin, 2008)

During the DAF process, a micro-sized bubble spray with diameters of 20µm to 120µm is produced from high pressured water spray in the range of 480 to 600 kPa. This micro-sized bubble spray caused sludge to float to the water surface. The sludge is then scraped and removed using mechanical scrappers or by flooding. Clarified water is drawn from the bottom of the flotation tank. Water treatment plant that uses this technology has several advantages such as time and space saving compared to plants that use old conventional technology (Lin, 2008).

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UF technology is another new technology used in Malaysia. Only 3 water treatment plant uses this technology throughout Malaysia. The first plant built started its operation in 2006 in Pulau Pinang while 2 other which are in Selangor started their operation in early 2008. UF technology plant uses complete filtration system to treat raw water. If for conventional method (including DAF technology) water must pass through sand filtration, while UF water treatment technology is nonconventional where water pass through membrane modules as illustrated in Figure 1.2.

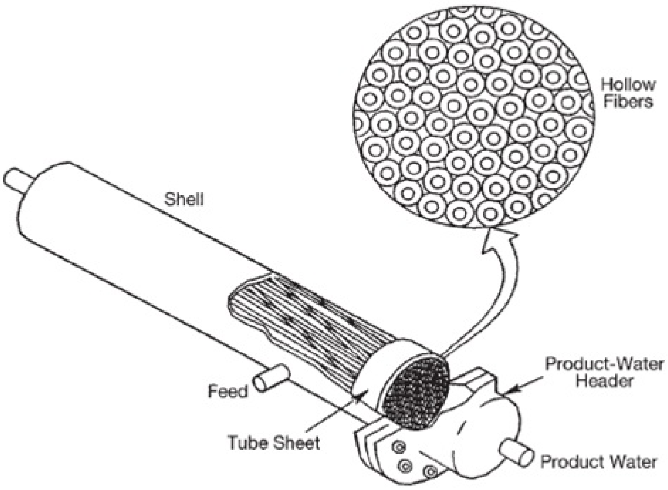

Fig. 1.2: Cutaway view of hollow-fiber membrane module (Chen, Honghui Mou, Lawrence K. Wang, & Matsuura, 2006)

The UF Module (Figure 1.2) can ensure that at least 99.99% removal of suspended solids, silt, colloidal matters, bacteria and protozoa with nominal pore size of 0.05 µm. (PBA, 2006). Among the advantages of using the UF technology is it could produce clean water of high quality, lower operation cost, easily upgradeable system and space reducing compact system. Figures 1.3 below illustrate the water treatment process using UF technology.

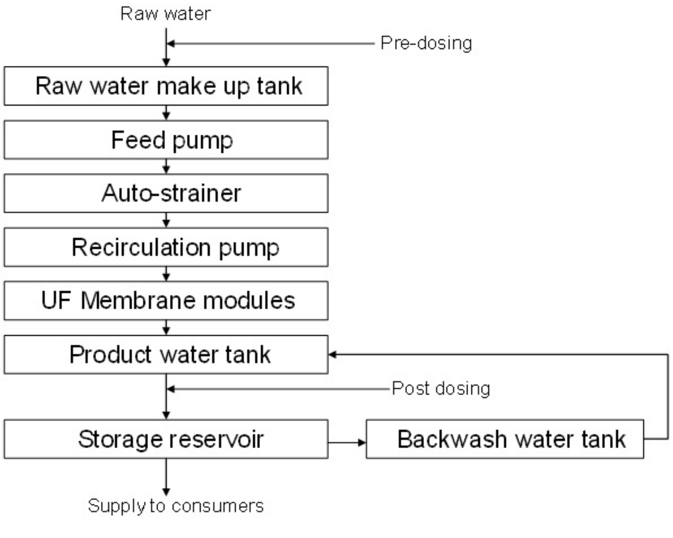

Fig. 1.3: Water treatment process using UF technology (PBA, 2006)

Both technologies mentioned earlier have advantages in the treated water production operation for consumers. But a study should be conducted on both technologies to identify the disadvantages that might caused adverse effects to the environmental quality or human health. For this purpose, the life cycle of both technologies are studied using the life cycle assessment (LCA) method.

There are several approaches in analyzing LCA that has been globally accepted. ISO Standards has issued a guide to a sound LCA analysis under the ISO 14000 series. To date, there are only two series of LCA approach (Finkbeiner, Inaba, Tan, Christiansen, & Klüppel, 2006) which is ISO 14040 (2006) and ISO 14044 (2006). ISO 14040 is the earlier version published in 1997 and it covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.

ISO 14044 (2006) on the other hand specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements. ISO 14040 and ISO 14044 approaches can be simplified as per figure 1.4.

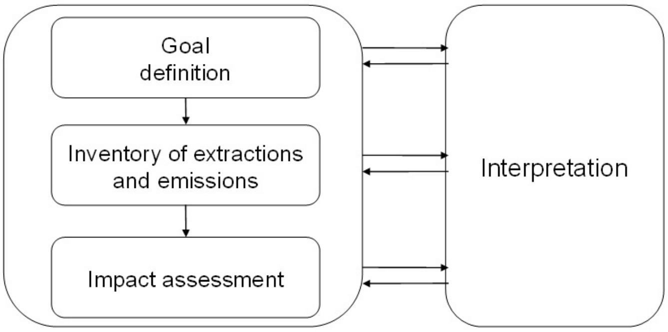

Fig. 1.4: Framework of Life Cycle Assessment (LCA) (Guinee, 2002)

Even though Malaysia has abundance water supply but demand for water such as in Kuala Lumpur and Selangor are increasing over time that it forces the construction of new plants and water reservoir to be undertaken. From the LCA perspective, supplying clean water that is in line with the standard set by the Ministry of Health Malaysia is a must but at the same time there is a need to ensure that the water treatment process does not caused adverse effects to the environment and human health. The potential of LCA as a tool in making sound decision in building new water treatment plants should be given due attention.

Goal and Scope of the Study:

The evaluation conducted on both types of water treatment technology is to illustrate to certain parties be it policy makers, environmental managers, engineers and stakeholders on the potential of LCA as a tool assisting in providing a holistic depiction generated from water treatment plant technology used. This is viewed as an important part so a better decision making in planning could be made should new water treatment plants to be built are adapted from environmental friendly technology. Apart from that, results of the impact analysis can have the potential to improve the weaknesses identified from each water treatment technology and minimized the environmental impact and eventually the well being of human.

To achieve the goal mentioned, a water treatment that uses both technologies discussed is chosen to depict the environmental impact from the process of producing drinking water to the quality set by the Ministry of Health Malaysia.

In a water treatment plant, there is 3 phases identified in a life cycle of the plant. The three phases are construction phase, production phase and decommissioning phase. This gate-to-gate study only focused on the production phase. System boundary for this study is illustrated in Figure 2.1 below.

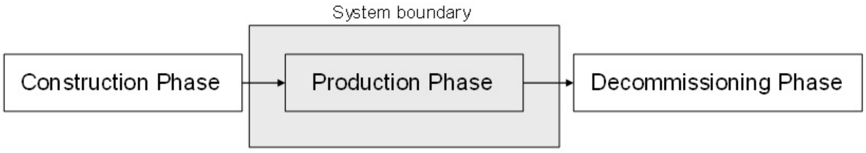

Fig. 2.1: System Boundary in Life Cycle Assessment in Potable Water Production

Functional unit used in this study is the quantity of drinking water produced on selected month according to the Malaysian National Drinking Water Quality Standards.

Life Cycle Inventory (LCI):

Data on chemical substances such as Aluminium Sulphate (Alum), Chlorine, Calcium Hydroxide (Lime) and electricity (refer Figure 3.1) utilize on the selected month are collected and analyze. Criteria for mass inclusion are:

- Include all unit processes up to 95% of the cumulative weight of the total product weight (cut off 5%).

If the unit process, however, is considered environmentally significant (e.g. toxic chemicals), the process is included in the product system.

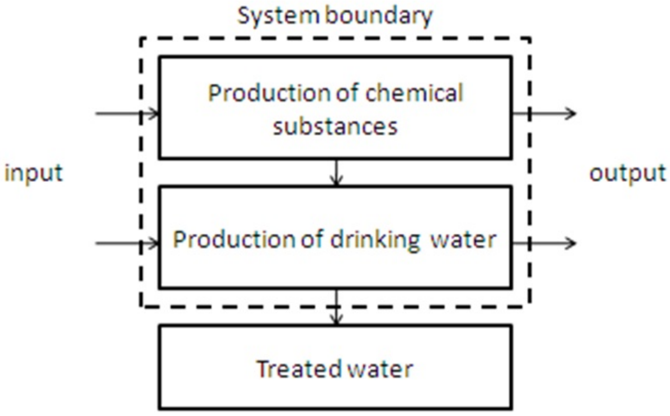

Fig. 3.1: The use of input and output inventory to illustrate impact

Table 3.1 shows the input inventories collected from studied water treatment plant. Inventories for collected input are values to produce 1000m^3 of treated water and inventories for output is acquired from the SimaPro7 database software.

Table 3.1: Life Cycle Inventory (LCI) for DAF and UF technologies input

	DAF	UF
Electrical consumption (kWH)	446.17	973.94
Alum (Aluminium Sulfate) (kg)	37.39	NA
Lime (kg)	32.75	NA
Chlorine (kg)	3.99	NA

Life Cycle Impact Assessment (LCIA):

This study is focused on the mandatory element only as set by ISO standard which includes classification and characterization element (ISO14000, 2000). In this working paper, the classification element is not shown. LCIA for this study uses the Eco-Indicator 99 method where it listed 11 impacts classified into 3 damage assessment (refer Table 4.1):

Table 4.1: Damage Assessment and Impact According to Eco-Indicator 99

Damage Assessment	Unit	Impact
Human Health	DALY	Carcinogen, radiation, respiratory organic and inorganic
Ecosystem Quality	PDF*m^{2}yr	Climate change, ozone layer and acidification,
	PAF*m^{2}yr	Ecotoxicity
Resources	MJ surplus	Land use, minerals and fossil fuels

(Goedkoop & Spriensma, 2001)

DALY	Disability Adjusted Life Years (Years of disabled living or years of life lost due to the impacts)
PAF	Potentially Affected Fraction (Animals affected by the impacts)
PDF	Potentially Disappeared Fraction (Plant species disappeared as result of the impacts)
SE	Surplus Energy (MJ) (Extra energy that future generations must use to excavate scarce resources)

Characterization:

The result of the analysis shows that DAF technology only supercedes UF technology in four impact categories namely radiation impact, land use impact, minerals impact and ozone layer depletion with values for radiation at 3.45E-08 on DALY unit (84.5% radiation contributed by Radon-222), land use at 0.107076

PDF*m^{2}yr unit, minerals at 0.023998 MJ surplus unit (78.7% is copper metal) and ozone layer depletion at 7.08E-09 on DALY unit as compared to UF technology that has the value of 0 or does not give any impact at all. Though UF technology impacted the ozone layer at about 25% (refer Figure 4.1) with a value of 1.82E-09 DALY unit, DAF technology has a higher value of 7.08E-09 DALY unit (96.7% contribution from chemicals such as methane, bromotrifluoro and Halon 1301)

Table 4.1: Characterization table comparing DAF and UF technologies with various impact categories

Impact category	Unit	DAF	UF
Carcinogens	DALY	8.09E-06	1.3E-05
Resp. organics	DALY	1.22E-07	1.82E-07
Resp. inorganics	DALY	0.000113	0.00015
Climate change	DALY	8.59E-05	0.000165
Radiation	DALY	3.45E-08	0
Ozone layer	DALY	7.08E-09	1.82E-09
Ecotoxicity	PAF*m^{2}yr	22.64513	38.69075
Acidification/ Eutrophication	PDF*m^{2}yr	5.094532	8.562155
Land use	PDF*m^{2}yr	0.107076	0
Minerals	MJ surplus	0.023998	0
Fossil fuels	MJ surplus	595.7215	1244.309

Several impact found to be more apparent in UF technology such as carcinogens, respiratory organics and inorganics, climate change, ecotoxicity, acidification/eutrophication and fossil fuels. For carcinogens category the difference between UF and DAF are about 37.8% (where UF contributes 1.3E-05 while DAF contributes 8.09E-06 on DALY unit). Most identified carcinogenic material are Arsenic at 83.1% for DAF and 87.6% for UF.

As for impact to respiratory organics, DAF contributes 67.07% compared to UF (DAF contributes 1.22E-07 DALY unit while UF contributes 1.82E-07 DALY unit). Non-methane volatile organic compound (NMVOC) material is identified as the main contributor for this category where the value is at 87.4% on DAF and 84.5% for UF.

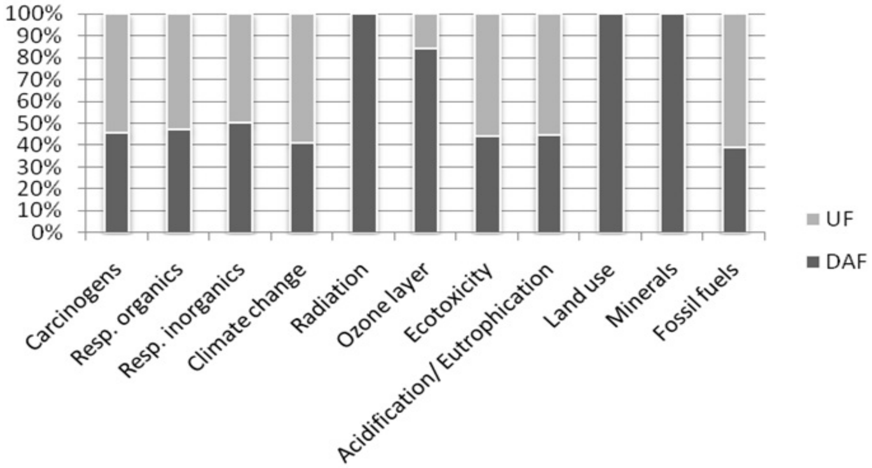

Fig. 4.1: Impact categories comparison graph (%) between DAF and UF technologies

Respiratory inorganic impact for UF is still high in comparison to DAF with 24.3% difference, meaning DAF contributes 75.01% at 0.000113 DALY unit while UF contributes 0.00015 DALY unit. The material that has been identified to contribute the most in this category is nitrogen oxides and sulfur oxides. Nitrogen oxides contributed higher from UF at 85.9% compared to 59.3% from DAF. However sulfur oxides values contributed higher by DAF at 35.3% compared to 9.4% from UF.

For climate change impact, it is UF that has a much higher impact compared to DAF. The difference of impact contribution by UF is a lot higher at 47.89% (0.000165 DALY) while DAF only contributes 8.59E-05 DALY. Carbon dioxide is the biggest contributor in climate change category with DAF contributing 95.4% carbon dioxide while UF contributes 95.1% carbon dioxide.

It is the same with fossil fuels impact. A significantly big difference is contributed by UF with percentage value for UF contribution is 100% (1244.309 MJ surplus) compared to DAF at only 47.89% (595.7215 unit MJ surplus).

Impact to Ecotoxicity and acidification/eutrophication however showed that impact value for both categories is still very low in DAF compared to UF. DAF contribution to the impact in both categories is 58.53% and 59.50% respectively compared to UF that contributes 38.69075 PAF*m^{2}yr for Ecotoxicity and 8.562155 PDF*m^{2}yr for acidification/eutrophication. Main material that contributes for ecotoxicity category is nickel. Nickel contributes 87.2% for UF and 78.5% for DAF. For damages caused by acidification/eutrophication, the main material that contributes is Nitrogen oxides at 96.8% from UF and 85% from DAF.

From the human health, ecosystem quality and resources impact categories perspective, UF technology contributes a clearly higher impact compared to DAF technology (refer Figure 4.2). Values for impact category of human health is 63.32% (0.000208 DALY), Ecosystem quality 60.06% (7.466121 PDF*m2yr) and resources contributes 47.89% (595.75% MJ surplus) compared to 100% value for all three categories contributed by UF.

Table 4.2: Comparison of Damage Assessment between DAF and UF

Damage category	Unit	DAF	UF
Human Health	DALY	0.000208	0.000328
Ecosystem Quality	PDF*m2yr	7.466121	12.43123
Resources	MJ surplus	595.7455	1244.309

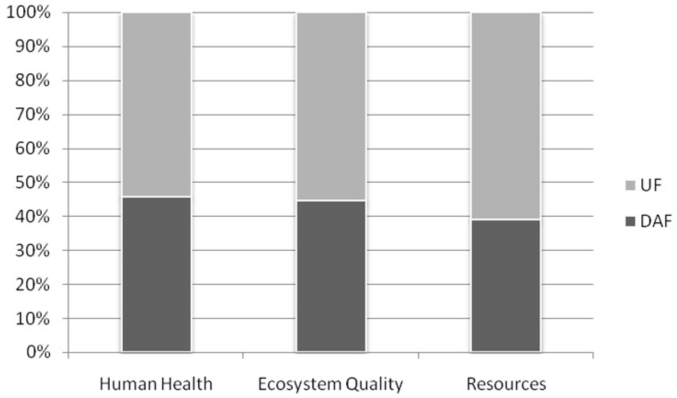

Fig. 4.2: Damage Assessment comparison between DAF and UF technologies (%)

The analysis of human health damage found that, a big part of material contributing for this category is carbon dioxide, nitrogen oxides and sulfur oxides. Table 4.3 shows the list of materials that contributed to impact damage category of human health. 39.48% carbon dioxide is contributed by DAF while 47.84% is contributed by UF. Meanwhile, nitrogen oxides contribution is at 32.38% and 39.25% by DAF and UF respectively. Sulfur oxides contribution from DAF is higher if compared to UF with the value of 19.27% compared to only 4.3%.

Table 4.3: List of materials that contributes to Human Health damage category (cut-off 0.1%)

No	Substance	Compartment	Unit	DAF	UF
1	Carbon dioxide	Air	%	39.48477	47.84631
2	Nitrogen oxides	Air	%	32.38397	39.2594
3	Sulfur oxides	Air	%	19.26611	4.298058
4	Arsenic, ion	Water	%	3.239797	3.473915
5	Particulates	Air	%	2.850887	2.130463
6	Methane	Air	%	1.801458	2.30707
7	Metals, unspecified	Air	%	0.349095	0.25463
8	Metallic ions, unspecified	Water	%	0.106625	0.117257
10	Remaining substances		%	0.517281	0.312896
	Total of all compartments		%	100	100

From analysis of environmental quality damage category (Table 4.3), three main materials are identified as the highest contributor namely nitrogen oxides, nickel and sulfur oxides. Nitrogen oxides in both technologies contributed more than half from the entire material that impacted to the decrease of environmental level. DAF technology contributes 58% nitrogen oxides while UF contributes 66.7%. Nickel is also a major contributor for this category with values of 23.81% for DAF and 27.14% for UF. However sulfur oxides are contributed higher in DAF at 10.21%. All materials such as Nitrogen oxides, Nickel and sulfur oxides are materials that decrease the environmental quality by polluting the air.

Table 4.3: List of materials that contributes to Ecosystem Quality damage category between DAF and UF (cut-of 0.1%)

No	Substance	Compartment	Unit	DAF	UF
1	Nitrogen oxides	Air	%	57.994	66.69121
2	Nickel	Air	%	23.81842	27.1454
3	Sulfur oxides	Air	%	10.21326	2.161298
4	Metals, unspecified	Air	%	3.554394	2.459257
5	Land use II-III	Raw	%	0.838737	x
6	Zinc	Air	%	0.806518	0.131777
7	Copper, ion	Water	%	0.503241	0.512502
8	Chromium	Water	%	0.418278	0.490335
9	Lead	Air	%	0.395181	0.071839
10	Land use III-IV	Raw	%	0.295011	x
11	Land use II-IV	Raw	%	0.292062	x
12	Cadmium	Air	%	0.145415	0.017313
13	Copper	Air	%	0.124594	x
14	Zinc, ion	Water	%	0.112501	0.114168
15	Nickel, ion	Water	%	0.109458	0.000502
16	Chromium	Air	%	0.103639	x
17	Remaining substances		%	0.275287	0.204403
	Total of all compartments		%	100	100

Damage category to source on the other hand sees natural gas as the main material component that contributes to this category with 96.6% in DAF and 99.03% in UF. Other materials contribute below 3% in both DAF and UF. Table 4.4 shows the list of materials that contributes in this category.

Table 4.4: List of materials contributing to Resources damage between DAF and UF

No	Substance	Compartment	Unit	DAF	UF
1	Gas, natural, 35 MJ per m3, in ground	Raw	%	96.63403	99.03308
2	Oil, crude, 42.6 MJ per kg, in ground	Raw	%	2.136671	0.298438
3	Coal, 18 MJ per kg, in ground	Raw	%	0.830153	0.668478
4	Gas, natural, 36.6 MJ per m3, in ground	Raw	%	0.367692	x
5	Remaining substances		%	0.031452	0
	Total of all compartments		%	100	100

Conclusions:

Electric usage is among the factor contributing to all three damage categories; environmental quality damage, human health damage and resource damage. But the electric usage in UF plant does not affect mineral, land use and radiation impact. Even though DAF method uses chemical materials such as alum, chlorine and lime but the impact towards environmental damage cannot compete with the damage contributed by UF except the ozone depletion category. As much as 64.3% material such as electricity from oil, heat oil and crude oil production contribute to the ozone damage originated from DAF. Something has to be done to ensure that the weaknesses in UF can be resolved from the aspect of high electricity usage. According to the Puncak Niaga Sdn Bhd, UF technology could ensure that there are no more water treatment plants that have to stop operating due to high NTU level surpassing 5 NTU during rainy season (Ibrahim, 2008). This shows that this technology is a better option than the conventional technology currently in use in Malaysia even with its weaknesses.

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