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Eco-friendly, strong alkaline water, emission and cooling

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THE ANALYSIS OF ENVIRONMENTAL AND HUMAN IMPACTS OF USING STRONG ALKALINE WATER FOR COOLING DURING MACHINING

An eco-friendly manufacturing approach is important for the environment. Enhancing machining performances is not only required to improve product's quality, time saving, and reduces costs; it is also contributed to the environmental protection efforts. Cooling is important aspect for obtaining this purpose. Therefore the benefits of Strong Alkaline Water (SAW) cooling method was assessed and compared with conventional wet cutting method. An experiment was performed at Nagaoka University of Technology machining centre. Three machine tools including a milling machine, a drilling machine and a turning machine were used. The study shows that using SAW for cooling is far more efficient than conventional cooling method. It reduces annual global warming potential by 72.95%, acidification potential 98.18%, ozone depletion potential 99.6%, smog formation potential 85.71% and human toxicity potential 42.86% compare with conventional method. The study concludes that besides inhibiting corrosion, prolonging tool life, improving surface roughness of final cutting and reducing energy usage, strong alkaline water cooling is an environmentally friendly approach and has positive impact on human health.

1. INTRODUCTION

An eco-friendly manufacturing approach is important to minimize damage to the environment and it has become a common request in industrial activities. Reducing energy consumption during manufacturing is one of the core aspects of this approach. It is believed that large consumption of energy and waste from machining has contributed significantly to the toxicity level in recent years. The emission of Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Nitrogen Oxide (NOx), and Non-Methane Volatile Organic Compounds (NMVOC) associated with energy usage during machining, waste disposal and transportation of goods has become a major issue in inducing global warming.

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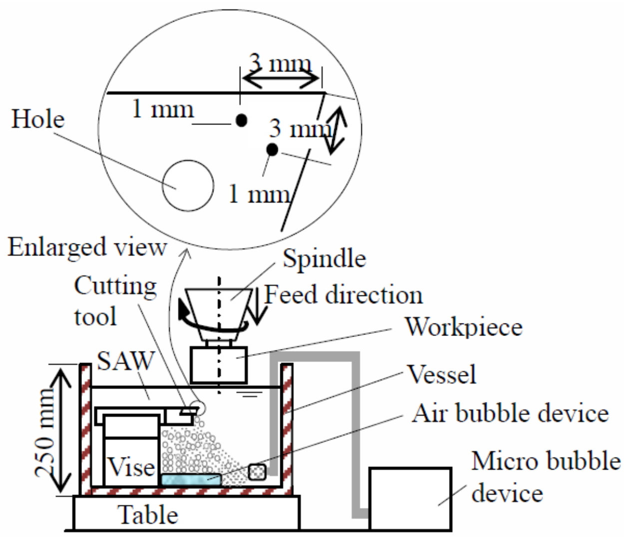
Hence, with the awareness of this global environmental issue, reducing emission has become one of the primary tasks in the industries and manufactures sector in nowadays [1,2].

Numerous studies on minimizing CO_2 emission during machining have been carried out and some researchers have explicitly investigated and designed environmental friendly grease and lubrication that has less of an impact on the environment [3,4-8]. Most of these studies proposed different methods by using different cutting fluid and coolant. However, the usage of cutting fluids during machining also has an effect on both the environment and on humans. So, a solution is required to minimize these impacts. Thus, in this paper the alternative cooling using Strong Alkaline Water (SAW) was proposed and evaluated by using several machine tools, assessing its environmental impacts from transportation and machining by applying a simple Life Cycle Assessment (LCA) method. Both raw material extractions and end product disposals were not considered in this study. Emission level of proposed cooling was compared with conventional cooling method. Based on the mentioned existing studies' parameters, the study found that using SAW reduces annual global warming potential by 72.95%, acidification 98.18%, ozone depletion 99.6%, smog formation 85.71%, eutrophication 50.0% and human toxicity potential by 42.86%. Thus it is concluded that SAW is an environmentally friendly cooling method that contributes less emission.

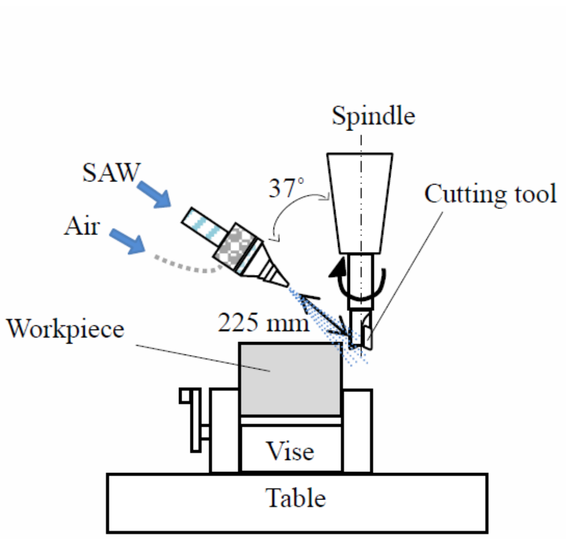
2. WET CUTTING USING STRONG ALKALINE WATER

Wet cutting using SAW is a new alternative cooling method which is considered as an effective and environmentally friendly approach [9]. It offers several benefits with specific characteristics. The property of SAW indicates that it contains 99.9% of water which has high specific heat, only 0.1% K_2CO_3 and it is best for medium cooling. The assistant compound is potassium carbonate (K_2CO_3). It has pH of 12.5, dynamic viscosity is 1.002×10^{-3} Pa·s, the specific heat is 4.184 J/g°C and it is colorless. The Fig.1 shows the schematic diagram how SAW is supplied to the cutting zones. The figure 1a is for measuring tool temperature and 1b for measuring tool life and surface roughness. In the Fig. 1a, the cutting tool and workpiece are immersed in the SAW meanwhile in the Fig. 1b, SAW is supplied to the surface of cutting tool and workpiece through a nozzle with support of air [10-12]. Some previous researches [9],[11] reported that the mixture of SAW with air produces high heat transfer coefficient compared to conventional cooling; hence it improves evaporation cooling effect. The high specific heat, it requires large amounts of heat to change the temperature of SAW and microbubble, therefore it can help cooling workpiece and tool for some period of time. Some important aspects such as inhibition of corrosion, longer tool life, reduction of thermal deformation of workpiece and better surface finishing can also be achieved by using SAW. It can inhibit corrosion to almost all related materials in machine tools as it has high pH concentration of 12.5 [13].

The corrosion properties of the common material used in the machine tool tested in various pH levels for two months. Normal water with pH 7.0, common alkaline water with pH 10.0, and SAW with pH 12.5 were used in the test. When various materials related to machine tools, except aluminum, were submerged into SAW for two months, they did not corrode. However, S45C and aluminum corroded in both normal water and alkaline water. Hence, it is considered that SAW is better at inhibiting corrosion compared to normal water with pH 7.0 and common alkaline water with pH 10.0. In addition, both copper and brass showed discoloration. Consequently, precaution is required during machining of both copper and brass. Besides improving cooling effect and inhibiting corrosion, the use of strong alkaline water can increase tool life, reduce thermal deformation of the workpiece and produce a better surface finishing.



a) Experimental set-up for measuring tool temperature [10,11]



b) Experimental set-up for measuring tool life and surface roughness [12]

Fig. 1. Schematic view of supplied SAW to the cutting zone

Study shows that cutting under SAW increases tool life by 2.4 times compared to conventional wet cutting [11]. Da Cruz (2014) states that selection of proper cutting conditions is very essential as can improve tool life [14]. The practical cutting conditions that considered in the previous studies were; first for Fig. 1a, cutting speed 80 m/min, feed speed 0.25 mm/rev, depth of cut was 0.4 mm, workpiece material was Ti6A14V with specific cutting force of 3178 N/mm^2 and the tool rake angle was 5º with coated carbide. Second the cutting condition for Fig.1b, cutting speed 100 m/min, feed per tooth 0.039 m/tooth, width of cut (axial) 2 mm, depth of cut (radial) 3 mm, workpiece material Ti6A14V with specific cutting force of 3420 N/mm^2, tip material coated carbide (S30T), tip coating PVD-TiA1N, rake angle 5º and clearance angle 21º [10,11]. The studies found that tool life is prolonged by 2.5 times when immersion of bench lathe is conducted and 2.6 times when using SAW with optimum air quantity [9,12]. Moreover, surface roughness of the final cutting is also improved. Thus, the application of SAW as coolant can give the best cooling effect, longer tool life, and improve the surface roughness of the finish. On the other hand, the impact of SAW on both environment and human health needs to be taken into account. Therefore, a simple assessment of these aspects was considered.

3. STUDY METHOD FOR THE ASSESSMENT OF SAW

3.1. AIM AND SCOPE OF STUDY

The goal of this study is to assess the impact of using SAW as a coolant for machining on both environment and human health. Fig. 2 shows the simplified flowchart of the life cycle of conventional wet cutting and SAW assisted cutting. The system boundary of this study includes the transportation of cutting fluid and the final use of the cutting fluid. All activities related to extraction and production of the raw material for workpiece and cutting tool, as well as raw material from crude oil were excluded. This study summarized the LCA of previous studies on SAW as cooling for milling, drilling and turning operations, where the bench lathe was immersed in a vessel of SAW [9-12]. The environmental impact in this study was focusing on the GHG emission during transportation and machining. It calculated the possible hazardous gases that emitted to the atmosphere from SAW and conventional cutting oil, as well as other lubricants during machining. In this paper, 1 km for transportation of SAW and one year machining operations of milling, drilling and turning for both cutting oil and SAW assisted cutting were chosen as functional unit. The amount of energy consumed was assessed and its gas emission level was calculated.

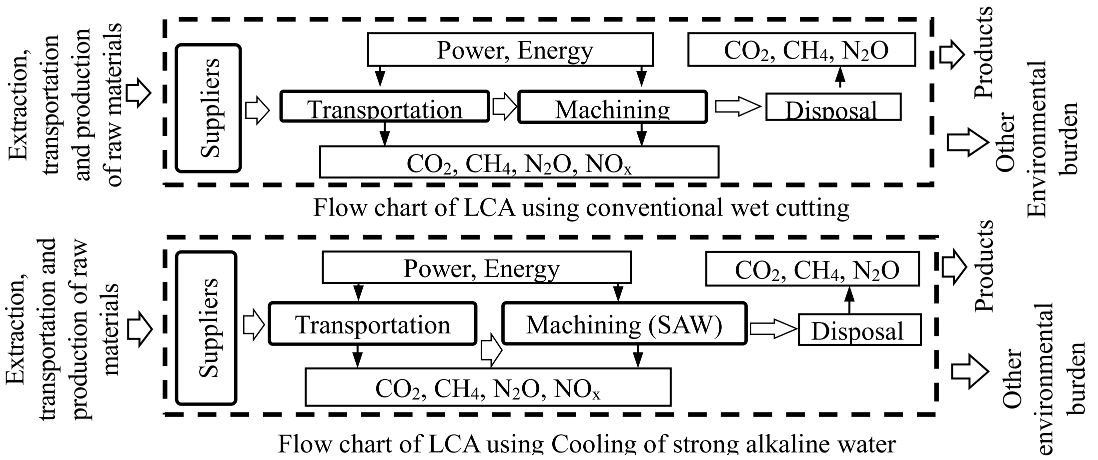


Fig. 2. Flow chart of LCA for conventional wet cutting and strong alkaline water

3.2. CALCULATION APPROACHES

The assessment was conducted by calculating the emission levels of various gases and the potential impact to the global warming, acidification, ozone depletion, smog formation, eutrophication and human toxicity. Calculation was focused on three main parts including 1) emission during transportation of tools and additive components of strong alkaline water and other related materials from suppliers to the machining site; 2) the emissions from power consumption during machining; and 3) oil disposal. The amount of CO_2, CH_4, N_2O, NOx, and NMVOC associated with exhaust emission from fuel consumption during road transportation were calculated by Eq. (1), while the emission from power consumption during machining was calculated by Eq. (2) [15]. Meanwhile the emissions from disposed oil were obtained from Eq.3 and 4. The CO_2 emission was calculated from Eq.3 and CH_4 and N_2O emissions were calculated from Eq.4.

$$\text{Exhaust emission (kg-}i\text{)} = \text{Distance traveled (km)} \times EF \text{ (kg/km)} \tag{1}$$

$$CL_i = EF \text{ (kg-}i\text{/kWh)} \times W_E \text{ (kWh)} \tag{2}$$

$$CO_2 \text{ emission (kg-}CO_2\text{)} = \text{Disposed oil (k}\ell\text{)} \times \text{Calorific value (GJ/k}\ell\text{)} \times \text{EF (t-C/TJ)} \times (44 \div 12) \tag{3}$$

$$E_i = \text{Oil (k}\ell\text{)} \times \text{Calorific value (GJ/k}\ell\text{)} \times EF \text{ (kg-}CH_4\text{/TJ, kg-}N_2O\text{ /TJ)} \tag{4}$$

In these calculations i represents emitted gas of CO_2, CH_4, N_2O, NOx, and NMVOC, EF is the emission factor for related gases, and W_E is the amount of power consumed in an hour and E_i is emission of CH_4 and N_2O (kg-CH_4, kg-N_2O). The emission factor of 1 km for transportation was based on the amount of energy from fuel consumption (diesel: 35.9 MJ/km and petrol: 32.7 MJ/km) [16]. In terms of the electric power consumed during machining, the emission factor was taken based on the amount of the gas emitted per kWh, while the emission factor for oil disposal was taken based on the amount of related gas emitted over energy usage during incineration of disposed oil. The estimation of the potential impact from the emission, such as global warming potential, acidification potential, ozone depletion potential and photochemical smog formation potential, were calculated based on the total emission from transportation, machining and oil disposal.

4. IMPACTS OF STRONG ALKALINE WATER

The impact of SAW to the environment and human health were inventoried and assessed. The study discusses the emission produced from transportations of consumable items and machining operations in the following sections of 4.1.1 and 4.1.2. Meanwhile the end disposal of SAW to the environment will be assessed in a different study.

4.1. IMPACT TO THE ENVIRONMENT?

4.1.1. IMPACT OF TRANSPORTATION

It has been reported that road transportation contributes 10.2%, while other transport contributes about 3.9% of direct emission to global emission according to the fifth report of IPCC [17]. As petrol and diesel are the main fuels that are used in road transportation, the emissions from these fuels were evaluated. This included the emissions from transporting of consumable elements such as cutting fluid, grease, cutting tool and others related materials for machining process that were ordered from various companies. The consumption of petrol and diesel every 1 km was collected and included exhaust emissions such as CO_2, CH_4, N_2O, NOx, Particulates and Non-Methane Volatile Organic Compounds (NMVOC). The exhaust emissions are obtained by using Eq. (1). Table 1 shows total emission and energy consumption level of 413 km (one way trip) travel distance from Tokyo to Nagaoka. This result was then multiplied with the frequency of the consumable items of machine tools and materials that were ordered in one year to obtain annual emission. Since the transportation of purchased materials is shared with other owners from different companies, the amount of emission was also shared accordingly. There are 217 metal working companies that exist in Nagaoka, Niigata Prefecture, Japan. Assuming that half of these companies use conventional wet cutting and the other half use SAW cutting, while around 10 companies' order same product at the same time, the transport emission would also be shared among these companies per shipping.

Table 1. Energy consumption and emission calculated during transportation from Tokyo to Nagaoka University of Technology

(a) Exhaust emission for 413 km

Exhaust emission gases	Emission factor (EF)*		Total emission (For 413 km)	
	Petrol kg/km	Diesel kg/km	Petrol kg	Diesel kg
CO_2	0.219	0.196	90.4	80.9
CH_4	3.50×10^{-5}	1.10×10^{-5}	0.0145	0.0045
N_2O	3.60×10^{-5}	3.50×10^{-5}	0.0149	0.0145
NO_x	2.20×10^{-5}	2.78×10^{-3}	9.09×10^{-3}	1.15
PM	0.50×10^{-8}	3.56×10^{-8}	2.07×10^{-6}	1.47×10^{-5}
NMVOC	0.80×10^{-5}	2.00×10^{-4}	3.3×10^{-3}	0.0826

*EF of CO_2 [18]; CH_4, N_2O, NO_x, and NMVOC [19] and PM [20]

(b) Energy consumption for 413 km

Fuel	Energy conversion factor, ECF MJ/km*	Total energy consumption for 413 km MJ
Petrol	32.7	13505
Diesel	35.9	14827

* Emission Coefficient Factor [16]

Table 2 shows the order frequencies of consumable items of machine tools and materials that need to be transported in a year. It was assumed that conventional wet cutting, cutting oil, lubrication oil, cutting tools and workpieces are transported annually to machine center workshops 12, 3, 2, and 12 times respectively. It was also assumed that the one year order frequency for consumable materials of SAW assisted cutting method are cutting tools 2 times, workpieces 12 times and POCA 2 times respectively. POCA is a compound of potassium carbonate (K_2CO_3) which ionized with water to generate SAW. Considering that 3 machine tools such as milling, drilling and turning machine were used, the total annual order frequency for conventional wet cutting was 87 times and for cutting of using SAW was 48 times.

Table 2. Frequencies of machine tools consumable order in one year for 1 company

Cooling type	Tools and consumables	Order frequency for 1 machine (times/year)	Total order frequency for 1 company and 3 machines (times/year)
Conventional wet cutting	Cutting oil	12	87
	Grease	3	
	Cutting tools	2	
	Workpieces	12	
Cutting using SAW	Cutting tools	2	48
	Workpieces	12	
	POCA	2	

Table 3. Total emission and energy consumption during transportation
(a) Total shared emission for 10 companies

Exhaust emission	Transportation for conventional cutting			Transportation for proposed SAW cutting		
	Petrol* kg/year	Diesel* kg/year	Exhaust quantity ** kg/year	Petrol* kg/year	Diesel* kg/year	Exhaust quantity ** kg/year
CO_2	1574	1409	1524	868	777	841
CH_4	0.250	0.079	0.20	0.139	0.04	0.11
N_2O	0.260	0.25	0.26	0.143	0.14	0.14
NO_x	0.160	20.0	6.11	0.087	11.0	3.37
PM	3.59×10^{-5}	2.56×10^{-4}	0.00010	1.98×10^{-5}	1.4×10^{-4}	0.00006
NMVOC	0.0570	1.44	0.47	0.032	0.79	0.26
Total shared emission kg			1531			845

*Emission = EF × Distance traveled × 2 × Order frequency / 10 companies ** This quantity is obtained based on the ratio of fuel type in Japan. The ratio of petrol and diesel is 70 to 30. Number of automobiles by fuel type [21].

(b) Total shared energy consumption for 10 companies

Description	Transportation for conventional		Transportation for SAW cutting	
	Petrol#	Diesel#	Petrol#	Diesel#
Energy MJ/year	234989	257985	129649	142336
Total shared energy MJ/year ##	241887		133455	

Energy usage = ECF × Distance traveled × 2 × Order frequency / 10 companies

This quantity is obtained based on the ratio of fuel type in Japan. The ratio of petrol and diesel is 70 to 30 Number of automobiles by fuel type [21].

Based on the assumptions made, the calculated result of total emission and energy consumption from transportation of the goods for 3 machine tools in one year is shown in Table 3. Table 3a shows the calculated result of shared emissions among 10 different companies for one year. The total emissions shared among these companies in a year for both SAW and conventional wet cutting were 1531 kg and 845 kg respectively. Table 3b shows the calculated result of shared energy among 10 companies for one year. It shows that the transportation of consumable goods for cutting using SAW consumes 44.8% less energy compared to the conventional wet cutting method. In addition, up to 108432 MJ of energy can also be saved when using SAW. These results were calculated based on the ratio of automobiles by fuel type in Japan between petrol and diesel that is 70 to 30 [21]. The comparison of total emission of various gases for the transportation of consumables and cutting tools for both cooling methods is shown in Fig. 3.

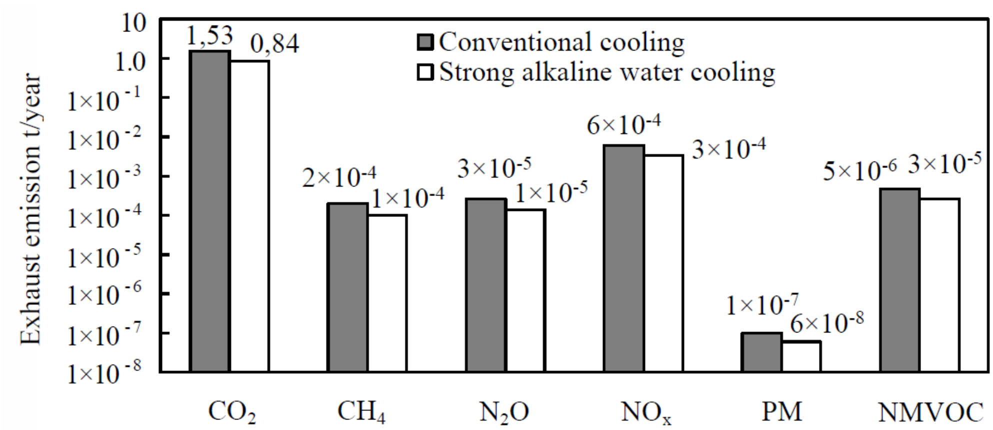


Fig. 3. Comparison of exhaust emission from different gas contents in one year for transportation of machine tool consumables

The calculated result shows that by using SAW for cooling, the CO_2 emission from transportation reduces from 1.53 tons to only 0.84 tons a year which is around 0.69 tons reduction compared to conventional wet cutting. It also reveals that carbon dioxide, methane, nitrous oxide, particulate matter and non-methane volatile organic compounds all reduce by 44.8%. This large reduction occurred due to the small amount of consumables materials that were needed for the cutting when using SAW compared to conventional wet cutting. Although this calculation was estimated for 10 companies, the amount of exhaust emission for transportation depends on the number of companies' order of consumables at the same time.

4.1.2. IMPACT OF MACHINING

The emission resulting from energy usage during the machining period was also calculated. Three different machines including milling, drilling and turning were used for the calculation. The emissions of CO_2, CH_4, and N_2O were obtained from Eq. (2). In this calculation, the emission factor was taken for each gas based on the amount of gas emitted during power usage per hour. The calculated result of emission from power consumed during machining in one year is shown in Table 4 and 5. Table 4 shows the annual emission of electric usage during machining using conventional wet cooling and Table 5 show the emission of electric usage for SAW cooling. The emission factor for CO_2 was taken from a Tokyo electric company [22] which is 0.600 kg-CO_2, while the emission factor of 7.09×10^{-6} kg-CH_4 and 3.96×10^{-6} kg-N_2O were taken based on emission per kWh of electricity generated in Japan for CH_4 and N_2O respectively [23]. In the case of using strong alkaline water, the total power consumed in one year was calculated based on electric usage of the machine tool, oil pump, microbubble device and strong alkaline water device.

Table 4. Emission from electric usage for conventional wet cutting

Exhaust emission	Emission factor* kg-i/kWh	Conventional cutting					
		Milling (3.6+1.2kW)		Drilling (0.75 +1.2+2.2kW)		Turning (0.75 +1.2+2.2kW)	
		Total Power kWh/year	Annual emission kg	Total Power kWh/year	Annual emission kg	Total Power kWh/year	Annual emission kg
CO_2	0.600	9600	5760	8300	4980	8300	4980
CH_4	7.09×10^{-6}		0.068		0.059		0.059
N_2O	3.96×10^{-6}		0.038		0.033		0.033
Total emission kg		5760		4980		4980	

*EF source: CO_2 [22]; CH_4 and N_2O [23] Note: Working days: 8 hr × 250 days

Table 5. Emission from electric usage for cutting using SAW

Exhaust emission	Emission factor* kg/kWh	Strong alkaline water cooling					
		Milling (3.6 +0.56+0.75+0.75 kW)		Drilling (0.75 +0.56+0.75+0.75 kW)		Turning (0.75 +0.56+0.0132+0.75 kW)	
		Total power kWh/year	Annual emission kg	Total power kWh	Annual emission kg	Total power kWh/year	Annual emission kg
CO_2	0.600	9839	5903	4139	2483	2706	1624
CH_4	7.09×10^{-6}		0.069		0.0294		0.0192
N_2O	3.96×10^{-6}		0.039		0.0164		0.0107
Total emission kg		5903		2483		1624	

*EF source: CO_2 [22]; CH_4 and N_2O [23] Note: work condition, working days: 8 hr × 250 days
SAW generator: 25 hr/ yr

In conventional wet cutting, 3.6 kW machining center and 1.2 kW oil pump were used for milling operations. 0.75 kW drilling machine, 1.2 kW oil pump and 2.2 kW oil cooling unit were used for drilling operations. In addition, 0.75 kW bench lathe machine, 1.2 kW oil pump and 2.2 kW oil cooling unit were used for turning operations. Assuming these three machine tools were operated for 8 hours per day and 250 days per year, the total power consumed for milling, drilling and turning machines was 9600 kWh/year, 8300 kWh/year and 8300 kWh/year respectively. Conversely, in the cooling method SAW water, 3.6 kW machining center and 0.75 kW drilling machine were used for milling and drilling process together with 0.56 kW microbubble device, 0.75 kW water supply pump and 0.75 kW SAW device. On the other hand, the 0.75 kW bench lathe machine, 0.56 kW micro-bubble device, 0.0132 kW chips removal pump and 0.75 kW strong alkaline water devices were used for turning process. The strong alkaline water producer machine generates 20 liters of strong alkaline water for about 2 hours 10 minutes and since water is changed once a month, it then takes 25 hr/year to generate SAW. Hence, the total power consumed by milling, drilling and turning operations using cooling of strong alkaline water for one year was 9839 kWh, 4139 kWh and 2706 kWh, respectively.

Table 6. Emission from Oil usage and disposal from conventional wet cutting

Emission gases	Emission factor* t-C/TJ, kg-CH_4/TJ, kg-N_2O/TJ	Calorific value MJ/ℓ	Conventional wet cutting					
			Milling		Drilling		Turning	
			Total disposed oil ℓ/year	Annual emission kg	Total disposed oil ℓ/year	Annual emission kg	Total disposed oil ℓ/year	Annual emission kg
CO_2	19.2	40.2	1040	2943	1040	2943	230	651
CH_4	0.83			34.7		34.7		7.67
N_2O	0.58			24.3		24.3		5.36
Total emission kg			3002		3002		664	

*Emission factor [19]

The results show that total emission emitted from three machining operations for conventional wet cutting is 15720 kg of emission and for SAW cutting is 10010 kg of emission. The 5710 kg of emission reduction in a year by cutting using SAW is an advantage for the environment. This benefit is even greater when the emission from used and disposal of cutting oil is included. Table 6 demonstrates the calculation result of emission from used and disposed oil. It uses Eq. (3) for calculating CO_2 emission and Eq. (4) for CH_4 and N_2O emissions. Since cutting using SAW does not require cutting oil, the calculation for oil usage and disposal was only applicable for conventional wet cutting. The emission factor for each gas in this part was taken from the Japan Ministry of the Environment Report, with calorific value of 40.2 MJ/ℓ was chosen for lubrication oil [19]. During machining, 680 ℓ of cutting oil is assumed to be used for milling and drilling in a year, while 170 ℓ /year is used for turning. It is also assumed that 360 ℓ, 360 ℓ and 60 ℓ of cutting oil are going to be used for refilling for milling, drilling and turning respectively. Taken together, the total amount of disposed oil was 1040 ℓ for both milling and drilling and 230 ℓ for turning. The total emission of the disposed oil for milling drilling and turning was 3002 kg, 3002 kg and 664 kg respectively. The comparison of the emission from transportation, machining and oil disposal of conventional wet cutting and cutting using SAW is shown in Fig.4.

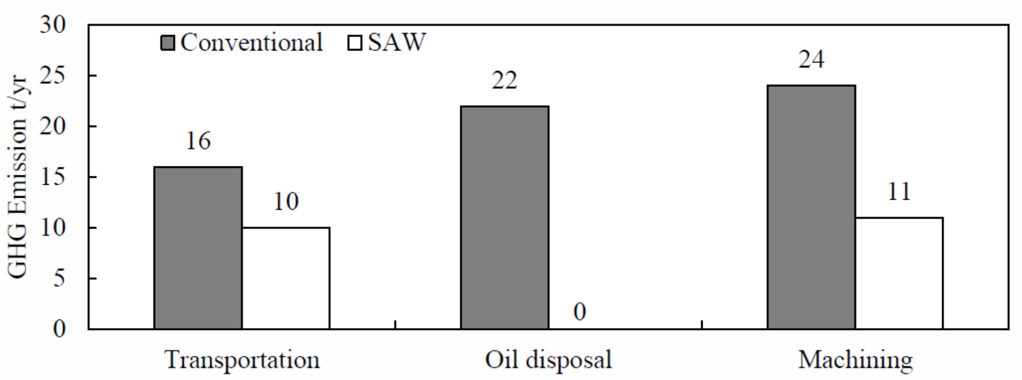


Fig. 4. Comparison of emission for conventional wet cutting and SAW assisted cutting (Transport emission is shared among 10 companies)

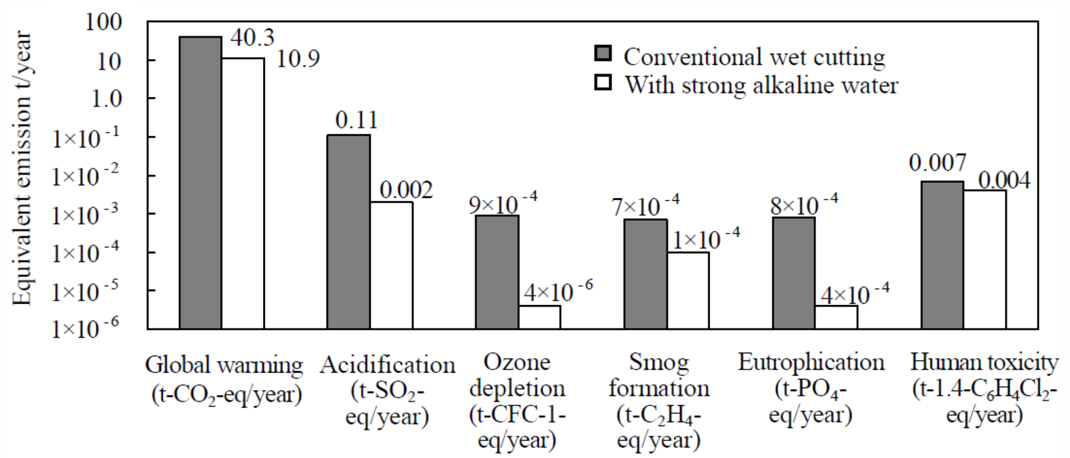


Fig. 5. Impact potential of emission for transportation machining and oil disposal for conventional wet cutting and cutting using strong alkaline water

Emission from the transportation sector was shared among 10 companies with the a-assumption that all companies order the same materials and consumables at the same time. The results showed that transportation emission for SAW is small compared to conventional wet cutting. By using SAW for machining, annual emission can be reduced up to 54.2% compared to the conventional wet cutting cooling system. By reducing the emission, its contribution to the global warming, acidification, ozone depletion and smog formation is also reduced. Fig.5 shows the potential impact of the emission from transportation, machining and oil disposal for conventional wet cutting and cutting using SAW. By using SAW as cutting fluid during machining, the potential impact of emission can be reduced to 29.4 t-CO_2-eq/year on global warming, 0.108 t-SO_2-eq/year on acidification, 0.894 kg-CFC-11-eq/year on ozone depletion, 0.6 kg-C_2H_4-eq/year on smog formation, 0.4 kg-PO_4-eq on eutrophication to the water and 30 kg-1.4-$C_6H_4Cl_2$-eq/year on the toxicities to the human health.

4.2. IMPACT TO THE HUMAN HEALTH

Besides the importance of environmental aspect, human health is also a key priority that requires significant attention. Thus the effect of SAW to the human health was considered. As explained earlier that the soluble compound used to produce SAW is 2.18 g/ℓ of Potassium Carbonate (K_2CO_3) which is 0.1% as the major portion of strong alkaline water is water (99.9%). Therefore, inhaling and skin contact during encountering with SAW is considered safe. Despite this, irritation to the skin may occur in some individuals and therefore precautions such as a wearing mask and washing hands and face after contact with strong alkaline water is highly recommended. In addition, drinking SAW is unsafe and should be avoided. Further investigation in the future is required to assess the impact of SAW to the human health specifically.

5. CONCLUSION

The results of this study are summarized as follow:

1. Transportation of consumable materials and tools produces highest emissions compare to machining operation, therefore fuel alternatives, travel routes and better shipping planning are required.
2. SAW reduces global warming potential by 72.95%, acidification by 98.18%, ozone depletion by 99.6%, smog formation by 85.71%, eutrophication by 50.0% and human toxicity by 42.86%.
3. Although SAW cooling is an environmentally friendly approach and has no serious effect on human health, further study on its human and end disposal to the environment impacts is strongly suggested.

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