2010 International workshop from the International Congress on Environmental Modeling and Software (iEMSs2010)

Application of Life Cycle Analysis (LCA) in evaluating energy-consuming of Integrated Oxidation Ditch (IOD)

Xianchun Tan[a,*], Junyi Xu[b], Sheng Wang[c]

[a]*Institute of Policy & Management, Chinese Academy of Sciences, Beijing, 100080 China;*
[b]*Municipal Works & Public Utility Design & Research Department, China Urban Construction Design & Research Institute, Beijing, 100029 China;*
[c]*Chongqing Academy of Social Science, Chongqing 400020, China;*

Abstract

With the research on some critical technology going deeply, the problem of technology route and project approach for the saving energy & reducing consumption have become the focus of municipal wastewater treatment process. In this article, LCA (Life Cycle Analysis) is applied to identify and compare the energy consumption of each stage of different technologies in municipal wastewater treatment from the view of whole process. This is carried out after reviewing the condition of energy utilizing of typical technologies in China. And some measures are brought forward to improve the efficiency of energy utilizing. Integrated Oxidation Ditch (IOD) is taken as an example and the energy consumption from its raw and processed materials exploitation, construction, treatment and running, rebuilding to its discarding and removing is identified and quantified, which is also compared with traditional treatment process of wastewater and waste sludge in China. This study shows that application of the high-energy-efficiency aeration device and optimizing control operation are essential paths to improve the energy consumption of IOD during its life cycle. And LCA is an important foundation of improving products quality and a main measure of sales promotion for manufacturers in recent years.

Keywords: Life Cycle Analysis (LCA); Integrated Oxidation Ditch (IOD); Energy-consuming; Wastewater treatment; Process; Efficiency

1. Preface

Environment, resources and population are the three main problems faced by the human beings [1]. Especially the environmental problems, with the increasing worsen degree, becomes a serious threat to the society survival and development [2]. The water pollution is the most obvious among all the environment problems [3-6]. The way to construct the wastewater treatment plant becomes one of the most important and the most effective measures for water pollution problem in city [7-10]. But along with the large-scale construction of wastewater treatment plant in the town, the enormous cost for wastewater treatment restricts the normal run of plant badly. The ratio of energy

---

* Corresponding author.
E-mail address: tanxianchun@yahoo.com.cn

consumption to the cost of wastewater treatment is 60% to 70% generally [11-14]. From the sustainable point of view, the huge energy consumption not only influences the wastewater treatment cost directly, but also influences the sustainable utilization of the energy and the resources. Moreover, it probably leads to new environmental problem during the energy product process [15]. Therefore, the energy consumption standard of municipal wastewater treatment process is becoming an important technology and environment quota, and attaches importance increasingly. How to research and explore the technology route and engineering way for saving and reducing energy of municipal wastewater treatment has very important signification. The emergence of any product in the final analysis is the input of energy. That the pollutant is removed also is the input of energy essentially. The energy input runs through course from beginning to end. Therefore, it is especially important to analyze energy based on the product life cycle.

So far, the energy analysis of the municipal wastewater treatment operation is confined to treatment process, without evaluating and demonstrating the whole process [11-13, 16]. Life Cycle Analysis (LCA) is a new system of environmental impact assessment techniques and methods, which based on the point of system, uses the technology facilities as the main line to collect, identify, quantify, analyze and assess resources consumption and the data and information of environmental impact of products throughout the life cycle, provides an environmental assessment tool of comprehensive, accuracy information [17- 20]. The traditional energy analysis method, which is techno-economic comparison of urban wastewater treatment, has been unable to meet energy analysis process requirements. The traditional technical and economic analysis often puzzles the owners entirely. And it is very difficult to make the decision; but the application of technical and economic analysis based on the Life Cycle Analysis will be research to the purpose of penetrating strong, convincing and scientific decision-making power.

Based on the philosophy of product life cycle, combined with request of "Discharge standard of pollutants for municipal wastewater treatment plant" of China, focused on newly integrated oxide ditch process which is run on the basis of multi-function of single tank section, this paper identifies and analyzes quantificational the whole energy consumption process from designation, exploitation and manufacturing of raw material, construction, handling, running, reconstruction and expansion of wastewater plant, abandoning and backout of Life Cycle Analysis (LCA). Meanwhile this paper compares this technique to traditional activated sludge system, which aims to bring out new technical economy and environmental assessment method [14].

2. Objective and Scope

2.1. The analyzed object of energy consumption based on the Life Cycle Analysis

In this paper, two kinds of index have been analyzed and compared based on the energy consumption of the wastewater treatment under different technology: (1) The energy consuming of wastewater treatment is converted into electric energy (kWh) or heat energy (kJ), and the consumed energy for treating per unit polluted water capacity(m^3) or removing per unit pollutant (COD or BOD) is calculated, namely, the energy consumption ratio; (2) The whole energy consuming every year of different wastewater treatment technology has been calculated in terms of the same scale and similar water quality condition.

The paper regards the XINDU wastewater treatment plant, which capacity is 10,000 m^3/d with IOD process, as analysed object of energy consumption based on the LCA. XINDU wastewater treatment plant is the model project for wastewater treatment in Sichuan province. The process flow is showed as Fig.1. The technology parameter as following: the total hydraulic retention time(*HRT*) of IOD is 15 hr, hereinto, anaerobic, anoxia and aerobic time are 1 hr, 2 hr and 12 hr respectively; The effective depth of water is 4.5 m inside the ditch, the width of single ditch is 10.5 m and the effective volume is 5953 m^3; the designed MLSS is 3000 mg/L, the sludge loading of BOD_5 is 0.1 kg BOD_5/kgMLSS·d) and sludge retention time(*SRT*) is 20 d; a 0.75 kW stirrer is fixed in anaerobic area, a 2.2 kW stirrer in anoxia area, 2 rotation brush aerator with 1.0 m diameter, 9.0 m length, in aerobic area. The power of each aerator is 45 kW. In addition, a 27.5 kW impeller is fixed under water. The water quality of the inlet and the outlet in this wastewater treatment plant as shown in Table 1:
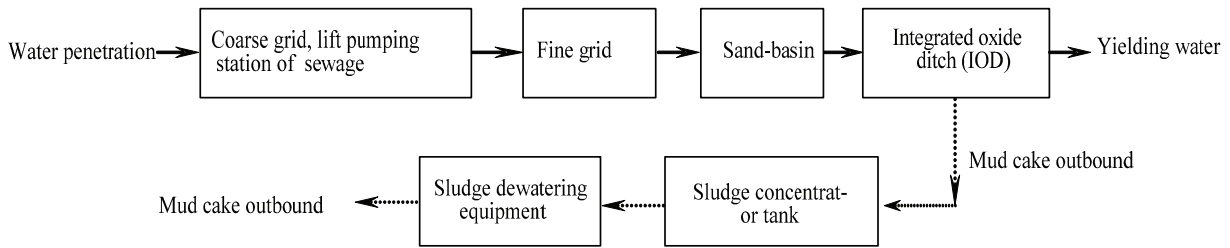
Fig. 1 The diagram of XINDU wastewater treatment technology process flow

The life cycle of IOD wastewater treatment system can be divided into three phases: namely, constructions phase, production phase and rejectamenta dismantling phase (in fact, the rejectamenta will not be dismantled, only a supposition according to the age limit), as shown in Fig.2:

Table 1.The inlet and outlet water quality of wastewater treatment plant

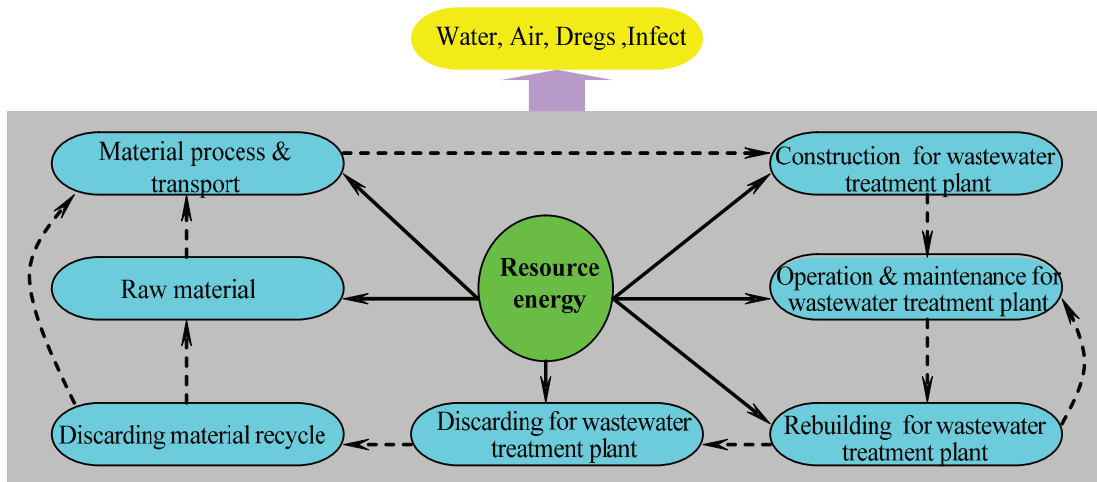| Parameter	COD_{Cr} (mg/L)	BOD_5 (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)
Water inlet	77.9-578	55-153	22-541	13-27.8	18-3 0.7	2.6-8.9
Water inlet average	197.4	73.2	123.1	20	23.4	5.8
Water outlet	26.0-46.0	9.2-20.6	3.0-21.0	0.8-2.3	3.1-12.4	1.1-5.5
Water outlet average	33.6	15.4	13.1	1.5	6.9	2.3

Fig. 2.The life cycle flow of IOD

2.2. The unit of LCA appraised function

It is well known that the consumptions and functions of a wastewater treatment plant's facilities have scale effects. The capacity of XINDU wastewater treatment plant is $1×10^4$, which is a typical wastewater treatment plant for small or middle town. This article uses such scale as the function unit for LCA analysis to compute the input and output of the wastewater treatment system. The traditional activated sludge process, which is used as a contrast, also applies this scale as the function unit, in order to make the two comparable.

2.3. The unit of LCA appraised function

According to the general urban planning, most of the city's wastewater treatment plants need to be rebuilt and updated to some extent with the increase of wastewater quantity and the increase of the discharge standard. For XINDU wastewater treatment plant, the short-range scale is $1×10^4$ and $5×10^4$ as a remote scale. Therefore, in the compare of the treatment facilities, the energy consumption problem should be considered in a 20 years' runtime.

3. The detailed analysis list of energy consumption

The knowledge base in this study was developed in three phases: knowledge acquisition, knowledge analysis, and knowledge representation. In the process of knowledge acquisition, the first author acted as the knowledge engineer and interacted with the domain expert in ITC, to acquire knowledge about problem-solving in the domain. During the phases of knowledge analysis and representation, the knowledge engineer analyzed the verbal information collected from the expert and configured them into a conceptual model. The Inferential Modeling Technique (IMT) [8,9] was applied in knowledge analysis and the knowledge was decomposed into the two levels of domain knowledge and task knowledge.

3.1. The input-output of wastewater treatment facility

During the life cycle of wastewater treatment facility, the energy, resource and the processing object input by environment and the contamination output to environment and their influence, are shown in Fig.3 .The resources input by the environment include the various raw materials as well as natural resources for material production, such as water, air, natural ore etc；raw wastewater is the research object. The energy sources include coal, petroleum and the electric energy etc, which are converted into Joule conformably. Other influences include noise, vibration, transportation, sight pollution, smell and ecology environmental pollution etc. The energy may be consumed in the life cycle of wastewater processing system and the items that should be considered are shown in Table 2.
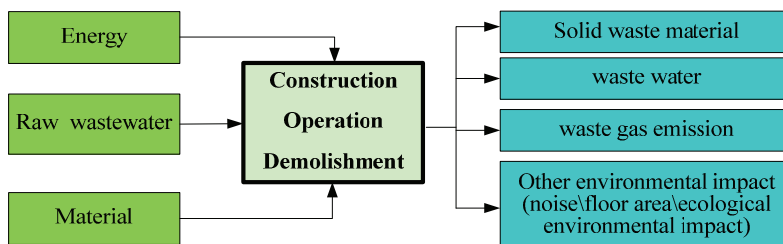

Fig. 3. The input-output chart of the wastewater treatment facility

Table 2.The probable energy consumption items during the life cycle of wastewater treatment system

Item	Construction stage	Operation stage	Demolishment stage

Raw material consumption	Steel, iron, cement, sand, water, PVC, copper, clay, bitumen, epoxide resin	Medicament etc	Topsoil、filling material etc
Energy consumption	Transportation, construct, mechanical dissipations	Power consumption, fuel, equipment dissipation	mechanical dissipations, fuel, etc

3.2. The energy consumption in the construction phase

The energy consumption during the construction phase includes raw material production, construction and transportation. The total energy of some kind of material is consisted of its natural calorific value and the energy consumption for production. Unified energy unit is adopted to quantify the different energy, for example, the electricity consumption is calculated according to the fuel thermal equivalent. When the thermo electrical conversion ratio is 32%, 1 is equal to 11080 .

According to quantities analysis and concerned standards, the building materials quantity of IOD can be calculated and the production energy consumption of IOD can also be quantified based on its material quantity and energy consumption for production. The construction energy consumption can be counted according to the construction area, 6640, and the construction energy consumption per unit area; the energy consumption for transportation building material can be counted according to the consumption amount of building material, transportation mileage, and energy consumption for transportation per unit.

Table 3.The total energy consumption in construction phase (Unit: 10^6KW·h)

Initial	Item	Integrated Oxide Ditch(IOD)	Traditional Activated Sludge Process(TASP)
1	Total energy of raw material	1.18	1.74
2	Total energy of communications and transportation	0.14	0.10
3	Total energy consumption for construction	0.647	0.51
4	Total energy consumption	1.967	2.35

3.3. The energy consumption in the running phase

The material consumption during running phase of treatment facilities is much low. The medicament consumption is the main portion. The energy consumption in this phase includes the power for wastewater treatment, the fuel and equipment loss for transportation, etc. Among them, the power consumption for wastewater treatment always occupy the total energy consumption more than 85%; in which, the electricity consumption of aeration systems is over 88.5%. The details of energy consumption of IOD are shown in Table 4.

Table 4.The list of main electrical equipments and energy consumption of process

No.	Building or process	Equipment	power	Designed Quantities (unit)	Designed Capacitor (kW)	Installed Quantities (unit)	Installed Capacitor (kW)	gross capacity installed (kW)	2. Actual power consumption (kWh/d)
I		Primary treatment (kW)						64.5	1152
1	Grid	Grid machine	1.5	3	4.5	3	4.5	4.5	
2	Wastewater pumping station	Lift pump	30	2	60	2	60	60	
II		Secondary treatment						110.15	1923.6

No.	Category	Item							
1	Integrated oxide ditch (IOD)	Brush aerator	45	2	90	2	90	90	
2	Integrated oxide ditch	Impeller under water	7.5	2	15	2	15	15	
3	(IOD)	Mixer under water	2.2	2	4.4	2	4.4	4.4	
4		Mixer under water	0.75	1	0.75	1	0.75	0.75	
III		Treatment & disposal for Sludge						3.3	79.2
1	Sludge dewatering building	Sludge pump	2.2	2	4.4	1	2.2	2.2	
2		Belt dewatering machine	1.1	2	2.2	1	1.1	1.1	
IV		Total							3154.8

3.4 The energy consumption of the demolishment phase

The energy consumption in the demolishment phase is related with the machine equipment for demolishment mostly, normally, which includes two parts: demolishment and transportation. The energy consumption of demolishment is 90% of the energy consumption of construction according to concerned document. The energy consumption of transportation for soil and filling material is calculated by construction area, the average density of soil and filling material (2.0 kg/m^3) and average transportation mileage (20 km).

The results of energy consumption under two different kinds of treatment technologies are listed in Table 5.

Table 5.The list of energy consumption of LC for two different technologies   (10^6 KW·h)

No.	The stage of LC	Item	Integrated Oxide Ditch(IOD)	Traditional Activated Sludge Process(TASP)
1	Construction	Raw material consumption	1.83	2.25
2		Energy consumption	1.967	2.35
3	Operation	Material consumption	2.61	4.09
		Energy consumption	6.08	17.11
4	Demolishment	Material consumption	0.01	0.01
		Energy consumption	0.601	0.46
5	Energy consumption of LC		8.648	19.92

Note: The aeration in IOD is intermittent while in TASP is continuous.

4. The LCA for the energy consumption of treatment technologies

4.1. The comparison of material consumption and energy consumption

From table 5, because of simple flow, few structures, no sludge digestion tank and little surplus sludge, the energy consumption of IOD is much less than TASP in construction and demolishment phases, and also is in running phase. From the point of view about energy consumption comparison, in the life cycle of IOD, the proportion of energy consumption of running is 40.16%, the energy consumption of material is 51.44%. The material consumption of IOD (including construction material and running material) surpasses the energy consumption of running which takes the second place and is one of the main energy consumption. Correspondingly, the main links is energy consumption of running for TASP, which occupies 65% to 75% energy consumption of TASP, while the material energy consumption only 21.1% to 29.3%.

From the comparison of energy consumption of life cycle based on two different kinds of technologies, the energy consumption of IOD is lower that the TASP by a wide margin holistically. The important cause of much lower energy consumption for the IOD depends on reducing energy consumption of running by a wide margin by

reforming running mode, from continuous flow and aerator to continuous flow with intermittent aerator, which makes the energy consumption 37.7% to 62% of TASP. The technology of continuous flow with intermittent aeration increases evidently the energy utilization ratio and service efficiency of wastewater biology treatment process. And its energy structure is reasonable. Counteracting the energy consumption of construction and demolishment, the whole energy consumption of LCA of IOD is still economical a lot, and lower than the TASP.

4.2 The analysis of the energy consumption ratio

Table 6. The ratio of energy utilization and energy consumption for two different technologies

Item			Integrated oxide ditch	Traditional activated sludge process
Total input Energy (kJ/d)	Matter entrapped energy (kJ/d）		73.29×10^6	105.04×10^6
	External energy	Aeration system (kJ/d)	20.74×10^6	13.43×10^6
		Other equipments (kJ/d）	0	28.04×10^6
	Total		94.03×10^6	146.05×10^6
Total available energy (kJ/d)	Techniques available energy (kJ/d)		45.32×10^6	54.02×10^6
	Total		45.32×10^6	54.02×10^6
energy usage ratio (%)			48.20	36.87
Comparable energy consumption (kW·h kgCOD)			1.54/0.233	2.05/0.31

It can be concluded from the table 6, the higher is the energy utilization ratio of wastewater treatment plant; the lower is the quota of energy consumption ratio generally. Both of the basic construction consumption and energy consumption of running are lower than the TASP because of the intrinsic property of IOD. As far as energy consumption, energy utilization and environmental impact caused by the energy produced process; the environmentalism of IOD is superior clearly to the TASP.

4.3 The analysis of energy saving measurement

According to the analysis results based on the LCA, the running energy consumption of IOD is major in life cycle. And two kinds of means for reducing energy cost, which is energy saving and load management, were put forward.

Energy saving, namely reducing the whole energy consumption, can be realized by the way of improving operation and raising the equipment efficiency. The course of dense energy of IOD is chiefly concentrated in the biology process unit, namely aeration system. To resolve the problem of low efficiency of aeration system or excessive aeration, the porous submerges diffuser or the air spray nozzle can be adopted to develop air bubble and transmit the oxygen to water. all practice from many countries has proved that the aeration machine of tiny pore can economize electrical consumption by more than 20%; secondly, running in the mode of continuous flow at with intermittent aeration, that is, aeration brusher combining impellers under water, can not only achieve the effect of energy saving and resolve the excessively supplying oxygen, but also can increase the function of biology processing system at the same time. (The practice has proved, the energy consumption is different in different running mode. The intermittent running mode with 2hr aeration and 1hr pause can save energy by 32%-43% than other modes. And the quality of outlet water can meet grade 1 standard of "Discharge standard of pollutants for municipal wastewater treatment plant" of China). For wastewater pumping system, we can use electrical machine of high efficiency to save energy.

5. Conclusion

Reducing the inside-consumption in wastewater treatment is one of the most important and the most effective measures for developing wastewater treatment plant and resolving water pollution in city. The idea of LCA is to

recognise and compare energy consumption in different phases of all kinds of different municipal wastewater treatment techniques. Based on this idea, several methods are put forward to improve energy efficiency. This paper, combined the requirement of China's GB18918-2006 standard, applied the thought of LCA, recognizes and quantizes the IOD in XINDU wastewater treatment plant in SiChuang province, China, from the stage of design, exploitation and machining of raw material to wastewater plant construction, running, reconstruction or extension, and demolishment, which had been compared with the TASP. The results show, the energy consumption of IOD during construction and running is lower than ordinary means of active sludge; and if reasonable running mode is applied, the energy consumption will be lower than the TASP. Using the running mode of 2 aeration and 1 pause, the energy consumption has been saved by 32%-45% than the latter, at the same time; the surplus sludge produce by IOD is reduced by 1/3 than other technologies, while the energy consumption ratio is raised by a wide margin. The results show that the IOD, because of its small land occupation, simple maintenance, little foul smell, and environmentalism, is superior clearly to the TASP.

References

[1]Kao JJ, Pan TC, Lin CM. An environmental sustainability based budget allocation system for regional water quality management. *Journal of Environmental Management* 2009;**90**:699–709.

[2] Jordan N, Boddy G, Broussard W, Glover JD, Keeney D, McCown BH, Mclsaac G, Muller M, Murray H, Neal J, Pansing C, Turner RE, Warner K, Wyse D. Sustainable development of the agricultural bio-economy. *Science* 2007;**316**:1570–1571.

[3] Ballo S, Liu M, Hou LJ, Chang J. Pollutants in stormwater runoff in Shanghai (China): Implications for management of urban runoff pollution. *Progress in natural sciences* 2009;**19**:873–880.

[4] Zhao LJ. Model of collective cooperation and reallocation of benefits related to conflicts over water pollution across regional boundaries in a Chinese river basin. *Environmental Modelling & software* 2009;**24**:603–610.

[5] Wang M, Webber M, Finlayson B, Barnett J. Rural industries and water pollution in China. *Journal of Environmental Management* 2008; **86**:648–659.

[6] Reddy VR, Behera B. Impact of water pollution on rural communities: an economic analysis. *Ecological economics* 2006;**58**:520–537.

[7] Osorio F, Torres JC. Biogas purification from anaerobic digestion in a wastewater treatment plant for biofuel production. *Renewable energy* 2009;**34**:2164–2171.

[8] Lew B, Cochva M, Lahav O. Potential effects of desalinated water quality on the operation stability of wastewater treatment plants. *Science of the total environment* 2009;**407**:2204–2410.

[9] Flores-Alsina X, Rodriguez-Roda I, Sin G, Gernaey KV. Multi-criteria evaluation of wastewater treatment plant control strategies under uncertainty. *Water Research* 2008;**42**:4485–4497.

[10] Oliveira SC, Sperling MV. Reliability analysis of wastewater treatment plants. *Water research* 2008;**42**:1182–1194

[11]J Hagan R M, Roberts E B. Energy Requirements for Wastewater Treatment (Part 2). *Water & Wastewater Works* 1976;**11**:52–57.

[12]Zarnett G D. Energy requirements for wastewater treatment equipment. *Applied Science Section, Pollution Control Branch*, Ministry of the Environment, Ontario,Can. TN7008 1976.

[13]Smith R．Electric power consumption for wastewater treatment: Cincinnati, Ohio: U. S. *Environmental Protection Agency,* EPA R2-73-281 1973.

[14]TAN Xianchun.Research on bio-phosphorus removal & energy saving in full-scale combined and integrated Oxidation ditch (CIOD). [*PH.D. Dissertation*].Chongqing University.2001

[15]Garcez CAG, Vianna JNS. Brazilian Biodiesel Policy: social and environmental considerations of sustainability. *Energy* 2009;**34**:645–654.

[16] Middlebrooks E J, Middlebrooks C H. Energy requirement for small wastewater treatment system. *Journal WPCF* 1981;**53**(7):1172–1197.

[17]Brehmer B, Struik PC, Sanders J. Using an energetic and energetic life cycle analysis to assessthe best application of legumes within a biobased economy. *Biomass and Bioenergy* 2008;**32**:1175–1186.

[18]Johns WR, Kokossis A, Thompson F. A flowsheeting approach to integrated life cycle analysis. *Chemical Engineering and Processing*. 2008;**47**:557–564.

[19]Huberman N, Pearlmutter D. A life-cycle energy analysis of building materials in the Negev desert. *Energy and Buildings* 2008;**40**:837–848.

[20]Ghertner DA, Fripp M. Trading away damage: quantifying environmental leakage through consumption-based, life-cycle analysis. *Ecological Economics* 2007; **63**:563–577.