

**Processed-based VOC emission characteristics, environmental
impact and health risk assessment in typical breweries in Beijing**

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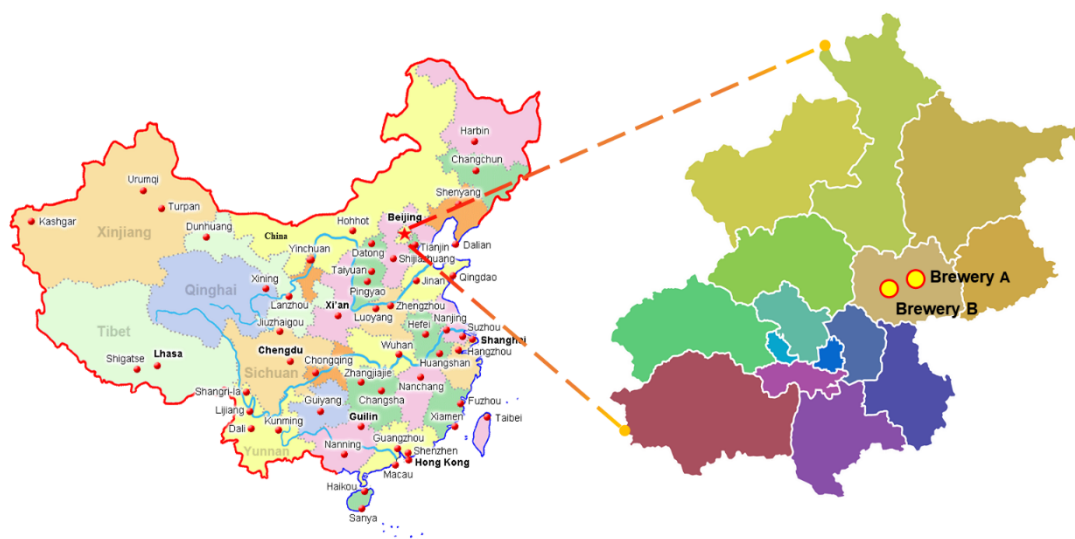


Figure S1. The locations of the breweries.

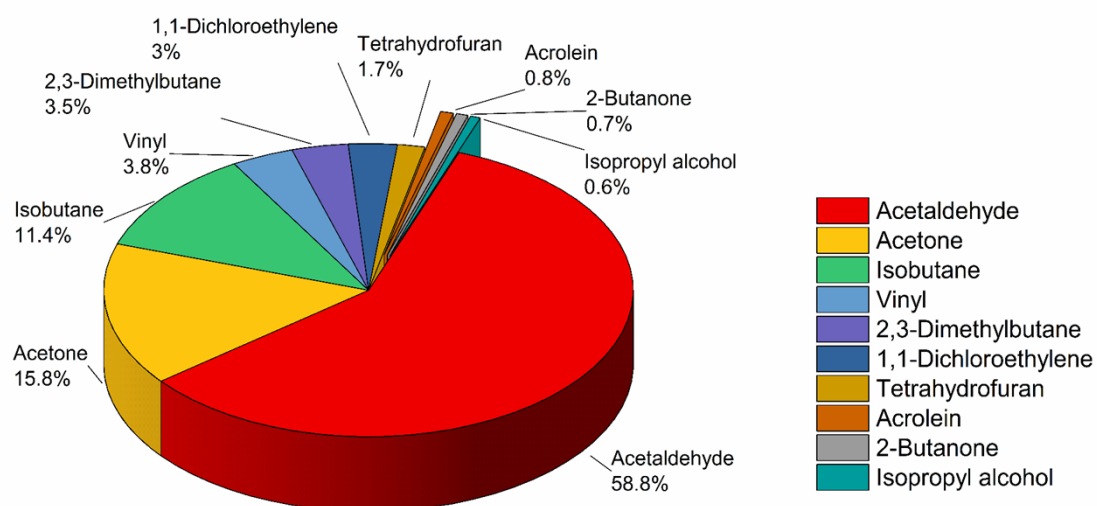


Figure S2. The percentages of the top ten VOCs during organized emission stages in brewery A.

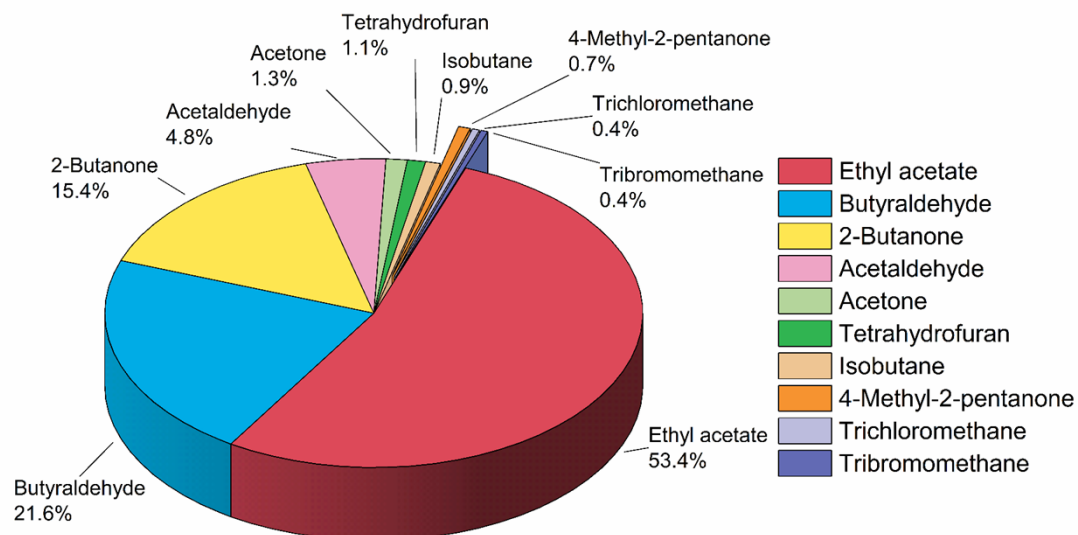


Figure S3. The percentages of the top ten VOCs during unorganized emission stages in brewery A.

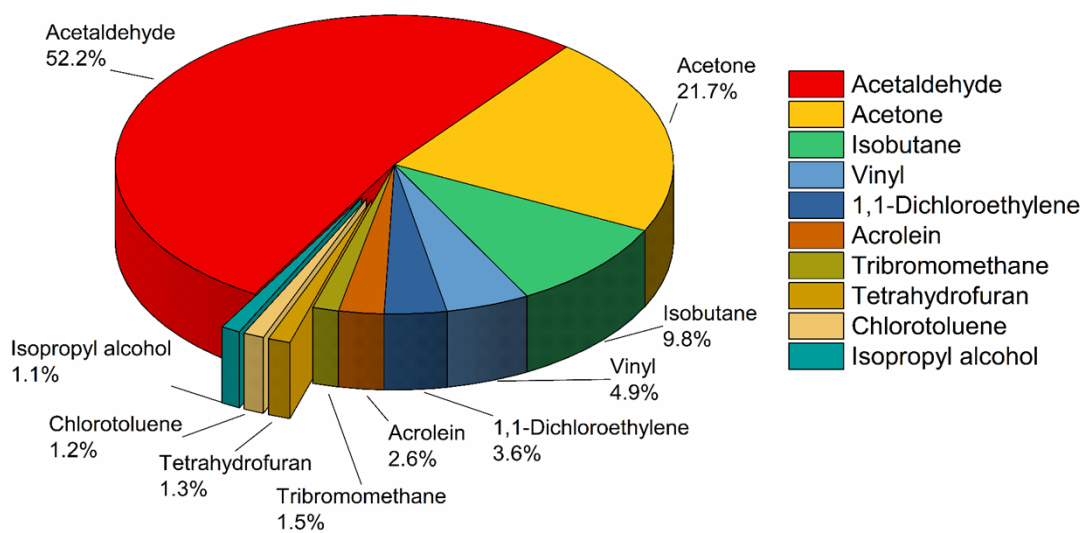


Figure S4. The percentages of the top ten VOCs during organized emission stages in brewery B.

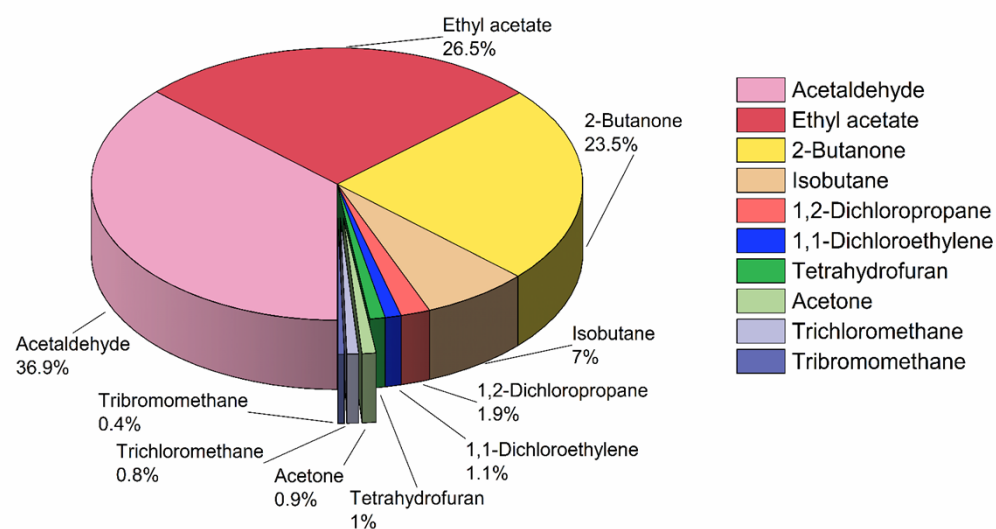


Figure S5. The percentages of the top ten VOCs during unorganized emission stages in brewery B.

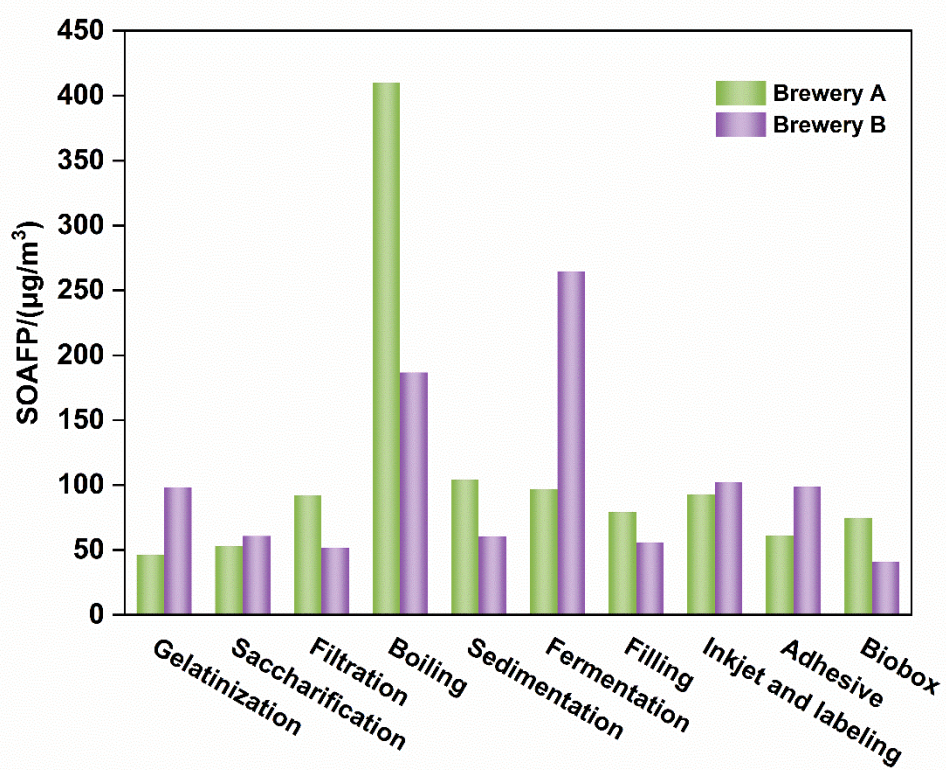


Figure S6. The concentrations of SOAFP in brewery A and brewery B.

Table S1. Comparison of Brewery A and Brewery B in terms of scale of production, technological details, and type of equipment.

Comparison	Aspects	Brewery A	Brewery B
Production scale and capacity	Yearly production	600,000 tons	100,000 tons
	Number of production lines	Four (Automatic)	Two (Semi-Automation)
	Saccharification temperature control	Multi-step temperature control	Single-step warming
Technological details	Hop Addition Methods	Staged approach	Add at once
Equipment type and contamination control	Types of fermenters	Stainless steel conical tank	Conventional open-top
	Boiling pot	Internally heated	Direct heating
	Exhaust gas treatment	Regenerative Thermal Oxidation	Activated carbon adsorption
	CIP system	Fully automatic closed cleaning	Manual high-pressure water flushing

Table S2. Types of measured VOCs, chemical categories, MIR values and SOAP values.

Categories	Name	MIR value	SOAP value
alkane	Ethane	0.28	0.1
alkane	Propane	0.49	0
alkane	Isobutane	1.23	0
alkane	n-Butane	1.15	-
alkane	Isopentane	1.45	0.2
alkane	n-Pentane	1.31	0.3
alkane	2,2-Dimethylbutane	1.17	-
alkane	Cyclopentane	2.39	-
alkane	2,3-Dimethylbutane	0.97	-
alkane	2-Methylpentane	1.5	-
alkane	3-Methylpentane	1.8	-
alkane	n-Hexane	1.24	0.1
alkane	2,4-Dimethylpentane	1.55	-
alkane	Methylcyclopentane	2.19	-
alkane	Cyclohexane	1.25	0
alkane	2-Methylhexane	1.19	0
alkane	2,3-Dimethylpentane	1.34	0
alkane	3-Methylhexane	1.61	0
alkane	2,2,4-Trimethylpentane	1.26	0
alkane	n-Heptane	1.07	0
alkane	Methylcyclohexane	1.7	2.7
alkane	2,3,4-Trimethylpentane	1.03	-
alkane	2-Methylheptane	1.07	-
alkane	3-Methylheptane	1.24	-
alkane	n-Octane	0.9	0.8
alkane	n-Nonane	0.78	1.9
alkane	n-Decane	0.68	2.4
alkane	n-Undecane	0.61	6.4
alkane	n-Dodecane	0.55	34.5
alkene	Ethylene	9	1.3
alkene	Propylene	11.66	-
alkene	1-Butene	9.73	1.2
alkene	cis-2-Butene	14.24	0.12

alkene	trans-2-Butene	15.16	0.12
alkene	1-Pentene	7.21	0
alkene	trans-2-Pentene	10.56	0.15
alkene	Isoprene	10.61	1.9
alkene	cis-2-Pentene	10.38	0.15
alkene	1-Hexene	5.49	0
alkene	1,3-Butadiene	12.61	0
alkyne	Acetylene	0.95	0.1
Aromatic hydrocarbon	Benzene	0.72	92.9
Aromatic hydrocarbon	Toluene	4	100
Aromatic hydrocarbon	m/p-Xylene	7.76	84.5
Aromatic hydrocarbon	Ethylbenzene	3.04	111.6
Aromatic hydrocarbon	Styrene	1.73	212.3
Aromatic hydrocarbon	o-Xylene	7.64	-
Aromatic hydrocarbon	Isopropylbenzene	2.52	-
Aromatic hydrocarbon	n-Propylbenzene	2.03	-
Aromatic hydrocarbon	o-Ethyltoluene	5.59	-
Aromatic hydrocarbon	m-Ethyltoluene	7.39	-
Aromatic hydrocarbon	1,3,5-Trimethylbenzene	11.76	-
Aromatic hydrocarbon	p-Ethyltoluene	4.44	-
Aromatic hydrocarbon	1,2,4-Trimethylbenzene	8.87	-
Aromatic hydrocarbon	1,2,3-Trimethylbenzene	11.97	-
Aromatic hydrocarbon	m-Diethylbenzene	7.1	-
Aromatic hydrocarbon	p-Diethylbenzene	4.43	-
Aromatic hydrocarbon	Naphthalene	3.34	-
Halogenated hydrocarbon	Chloromethane	0.04	-
Halogenated hydrocarbon	Vinyl chloride	2.83	-
Halogenated hydrocarbon	Chlorethane	0.29	-
Halogenated hydrocarbon	1,1-Dichlorethene	1.79	-
Halogenated hydrocarbon	Methylene chloride	0.04	-
Halogenated hydrocarbon	1,1-Dichloroethane	0.07	-
Halogenated hydrocarbon	trans-1,2-Dichloroethene	1.7	-
Halogenated hydrocarbon	Trichloromethane	0.02	-
Halogenated hydrocarbon	1,2-Dichloroethane	0.21	-
Halogenated hydrocarbon	Trichloroethene	0.64	-

Halogenated hydrocarbon	1,2-Dichloropropane	0.29	-
Halogenated hydrocarbon	cis-1,3-Dichloropropene	3.7	-
Halogenated hydrocarbon	trans-1,3-Dichloropropene	5.03	-
Halogenated hydrocarbon	1,1,2-Trichloroethane	0.09	-
Halogenated hydrocarbon	Tetrachloroethene	0.03	-
Halogenated hydrocarbon	Ethylene dibromide	0.1	-
Halogenated hydrocarbon	Chlorobenzene	0.32	-
Halogenated hydrocarbon	1,4-Dichlorobenzene	0.18	-
Halogenated hydrocarbon	1,2-Dichlorobenzene	0.18	-
OVOCs	Acetaldehyde	6.54	0.6
OVOCs	Acrolein	7.45	-
OVOCs	Acetone	0.36	0.3
OVOCs	Propionaldehyde	7.08	0.5
OVOCs	methacrylaldehyde	6.01	-
OVOCs	2-Butanone	1.48	0.6
OVOCs	Butyraldehyde	5.97	0
OVOCs	Pentanal	5.08	0
OVOCs	Hexaldehyde	4.35	0
OVOCs	2-Propanol	0.61	0.4
OVOCs	2-Methoxy-2-methylpropane	0.73	0
OVOCs	Vinyl acetate	3.2	-
OVOCs	Ethyl acetate	0.63	0.1
OVOCs	Tetrahydrofuran	4.31	-
OVOCs	Methyl methacrylate	15.61	-
OVOCs	1,4-Dioxane	2.62	-
OVOCs	4-Methyl-2-pentanone	3.88	0.6
OVOCs	2-Hexanone	3.14	0

Table S3. AERMOD input parameters for the representative emission source

	Brewery A	Brewery B
TVOCs($\mu\text{g}/\text{m}^3$)	17524.43	5757.64
Coordinate	116.69°E , 40.10°N	116.66°E , 40.17°N
Exit Temperature (°C)	80	75
Stack Height (m)	15	15
Stack Diameter (m)	0.6	0.5
Exit Velocity (m/s)	14	12
Emission Rate (g/s)	0.277	0.054

Table S4. Carcinogenic risk assessment results of the VOCs.

Species	RfC(mg/m^3)	HQ	
		brewery A	brewery B
Trichloromethane	2.30E-05	1.05E-09	—
Dichloromethane	1.00E-08	—	1.87E-05
Carbon tetrachloride	6.00E-06	4.33E-08	1.21E-07
Bromodichloromethane	2.00E-05	6.33E-06	6.34E-06
Bromoform	1.10E-06	3.31E-06	3.32E-06
Acetaldehyde	2.20E-06	7.67E-05	5.75E-04
Benzene	7.80E-06	1.40E-07	1.74E-06
Styrene	2.60E-05	2.25E-05	2.15E-05
Ethylbenzene	2.50E-06	3.92E-07	3.89E-07