ACADEMIA ROMÂNĂ
Revue Roumaine de Chimie
http://web.icf.ro/rrch/

Rev. Roum. Chim.,
2016, *61*(1), 67-74

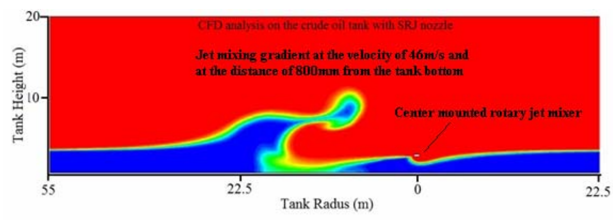
INTRODUCING NEW RELATION TO ESTIMATE MIXING TIME OF CRUDE OIL TANK HAVING SUBMERGED ROTARY JET MIXER

Ali Akbar Lotfi NEYESTANAK,[a,*] Ghasem ASADI[b] and Saeed DANESHMAND[c]

[a] Department of Engineering, Yadegar -e- Imam Khomeini (RAH) Branch, Islamic Azad University, Tehran, Iran
[b] Shift Repair Chief Engineer, Iranian Oil Pipeline Tehran District (IOPTC), Tehran, Iran
[c] Department of Mechanical Engineering, Majlesi Branch, Islamic Azad University, Isfahan, Iran

Received November 25, 2015

One of the most important design parameters for a crude oil tank equipped with a jet mixer is mixing time so it would be useful to study mixing time before designing the jet mixer of a tank. Nowadays, it is so necessary to apply submerged rotary jet mixer (RJM) to have a complete mixing in large crude oil tanks because in addition to the energy and economical issues there is a big amount of sludge on the bottom of the storage tanks. At present, there is no relation for mixing time of RJM just for fixed jet mixer. This study introduces a new theoretical relation to calculate the mixing time of crude oil tank having RJM and by identifying main parameters such as tank Radius, RJM dimensions, nozzle diameter, and blades angle of turbine it's possible to know the effect of these parameters on the mixing time. The relation obtained by real experimental results has been verified by use of CFD analysis and the results of the manufacturers of these machines.



INTRODUCTION

In jet mixing, a part of the fluid existing in the tank moves with high velocity into the tank by use of a pump and through nozzles, the critical velocity of a typical crude oil required to keep sheared wax particles in suspension appears to be 0.6 – 1.2 m/sec.[1] The jet fluid circulates in the surrounding fluid and makes a rotational pattern, which causes mixing inside the tank. Jet mixers have more advantages compared with impellers. They are installed easier and jet mixing remains less dead zones in the rectangular and shallow tanks than mixers.[2] Jet mixer is more efficient if cutting is needed besides mixing. In the gas/fluid systems, jet mixers use 20-40% less energy. Many researches have been done on jet mixing for 50 years and there are some experimental relations. It is rather complicated to choose an accurate one among these relations for a real case. Therefore, it is necessary to know the limitations of relations before applying them in designing the mixing process by jet. Now use of CFD has been succeeded in dealing with unchangeable limitations of experimental methods, in addition, complete studies have done by applying this system in jet mixing so design of jet mixing will be improved in near future.[3] Mixing time is one of the main design parameters in jet mixers. There are many results about measuring the mixing time of jet in tanks. All experimental relations for mixing time of fixed jet mixers are in Table 1.[4] According to Table 1, there is no specific relation to calculate mixing time of these machines and it indicates the relative main parameters. In this paper, a new relation will be presented and we will discuss on parameters such as tank radius, nozzle diameter and angle turbine of blade.

[*] Corresponding author: aklotfi@gmail.com

Table 1

The related equations to mixing time of fixed jet mixers[4]

Specifications	Relation	Dimensions	Geometry or construction of jet	Author
Mixing time does not relate to liquid height.	$t_{mix} \quad C_P \frac{D^2}{v_j d_j}$ $C_P \quad 9, \text{ when } t_{inj} \quad \frac{t_{mix}}{2}$ $C_P \quad 4.5, \text{ when } t_{inj} \quad \frac{t_{mix}}{2}$	D=1.52m H=0.9144m d_j=1.9mm d_0=2.54cm $\Theta = 40$	Inclined side-entry jet and cylindrical tank	Fosset
There is no exact criteria for mixing degree.	$t_{mix} \quad f \frac{H^{0.5} D}{v_j d_j^{\frac{4}{6}} g^{\frac{1}{6}}}$	D 0.29 &1.52*m*	Side-entry jet cylindrical tank	Gex and Fox
A model was developed and results were compared.	$t_{mix} \quad \frac{0.658}{v_j} \frac{\rho_c}{\rho_d}^{\frac{5}{8}} d_j^{0.25}$ $\frac{v_j}{N_j A}^{\frac{3}{4}} \quad Log \; 1 \quad c^*$	-	-	Lehrer
The recommended design height is not accurate.	$t_{mix} \quad f \frac{H^{0.5} D}{v_j d_j^{0.667} g^{0.166}}$	For side-entry jets: D 0.31 0.57m $\frac{H}{D}$ 0.9 1.1m For axial jets: D 0.31 0.57m $\frac{H}{D}$ 0.5 3.0m Re_j 250 60,000m	Side-entry and axial jets and cylindrical tank	Rice and Lane
Some suggestions for the depth of the optimum nozzle in circulation flow regime.	$\frac{t_{mix}}{t_r} \quad \frac{L}{d_j} \quad 2.5 \quad 8.0$ Re_j 30.000	D 56,104cm H 84,125cm h_i, h_o 4,14,24,44,74,94 D 104cm h_i, h_o 4.38,20.5,48.5 D 56cm d_j 0.5,1,1.8 θ 7,15,30,45,54,60,73	Side-entry jet cylindrical tank	Maruyama
It is only for steady and unsteady jets.	$M \quad t_{mix} \; gH^{0.5} \; DJ_s^{\frac{2}{3}} \quad 1$ $J_s \quad \frac{J}{\rho v_j g}, J \quad \rho A v_j^2$	D,H 490mm d_j 10mm	Two horizontal jets at H/3andH/2	Fonade and Simon
The effect of viscosity on mixing time has been studied.	$M \quad \frac{v_{mix}}{t_r} \; J_s^{0.41} \quad 11.3$ $t_r \quad \frac{D}{gH^{0.5}}$	D,H 500mm d_j 9,15mm	Two horizontal jets at H/3andH/2	Orfaniotis

Table 1 (continued)

The effect of jet angle is not considered.	$t_{mix} \quad 3\frac{L^2}{v_j d_j}$	D 0.61 36m $\frac{H}{D}$ 0.2 1.0m d_j 5.8 50mm v_j 2.2 24.8m/s	Cylindrical tank	Grenville and Tilton
The effect of jet angle is considered. Reliable correlation.	$t_{mix} \quad k\frac{D^2 H}{v_j d_j L}$ k 9.34, θ 15 k 13.8, θ 15	D 0.61 36m $\frac{H}{D}$ 0.2 1.0m d_j 5.8 50mm v_j 2.2 24.8m/s	Cylindrical tank	Grenville and Tilton

MEASURING THE MIXING TIME OF RJM

Because of effective mixing of sludge in the crude oil tank having RJM (Fig.1) the effective flow (Q) of pumping system should follow equation 1: [5]

$$Q = 7.56d^2\left(\frac{R}{d}\right)^{1.01} \tag{1}$$

According to the equation 2, this flow enters the machine and the velocity of input flow in the turbine will reach to V:

$$V = \frac{4Q}{\pi \times D^2} \tag{2}$$

Pitch speed of turbine (v_t) will be measured by equation 3, where blade angle deviation is:

$$V_t = V \times \mathrm{tag}\theta \tag{3}$$

According to equation 4, pitch speed of turbine gives rotational velocity (N) to it:

$$N = \frac{V_t \times \gamma \times 60}{D_t} \tag{4}$$

The slip factor of blades is (γ) calculated by equation 5 [6]

$$\gamma = 1 - \frac{\sqrt{\sin\theta}}{Z^{0.7}} \tag{5}$$

By use of total reduction ratio of Gearbox, (I) the required time for one Revolution of RJM (t_1) will be given by equation 6:

$$t_1 = \frac{I}{N} \tag{6}$$

Finally, by considering the above-mentioned relations and the necessary unitary transformation the required time for a complete turn of machine will be given by equation 7:

$$t_1 = \frac{D^2 D_t I}{ud^{0.99} R^{1.01}\mathrm{tag}\theta\left(1 - \frac{\sqrt{\sin\theta}}{Z^{0.7}}\right)} \tag{7}$$

For the proper mixing of crude oil tanks, the nozzle should have C complete turns in each starting (20 turns[7]-8 turns[8]) so it comes to equation 8. All these parameters listed in Table 2.

$$t = Ct_1 \tag{8}$$

Table 2

Parameters in use

N.	Specification	Unit	Parameter
1	Mixing time of a tank having RJM	hour	t
2	Diameter of RJM input	meter	D
3	Diameter of RJMTurbine input	meter	D_t
4	Total reduction ratio of Gearbox	-	I
5	The required turns for proper mixing	-	C
6	Constant number of unitary transformation	-	U
7	Output diameter of RJM nozzle	meter	d
8	Tank radius	meter	R
9	Deviation angle of RJM turbine blades	degree	θ
10	Blades number of RJM turbine	-	Z

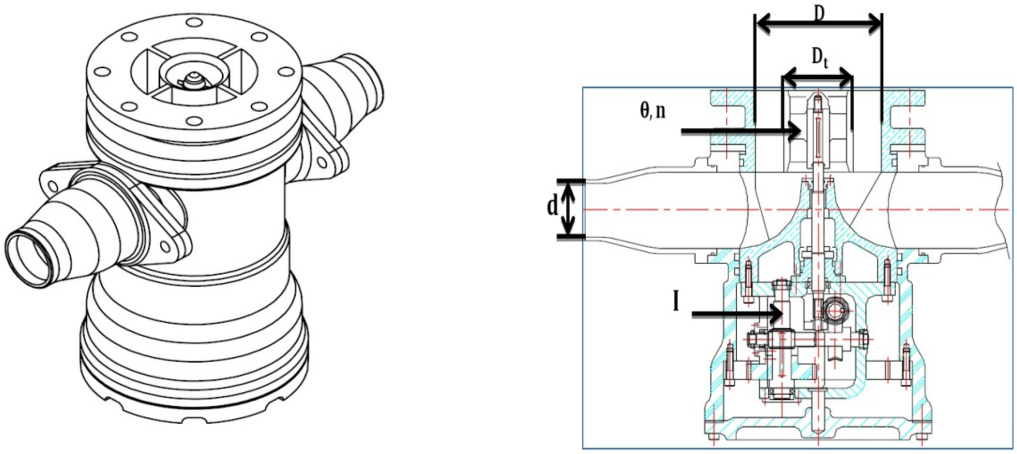


Fig. 1 – Rotary jet mixer machine (RJM).

STUDYING THE EFFECT OF TANK DIAMETER ON MIXING TIME

The geometrical parameters in Table 3 are normal sizes of a typical RJM system. Using RJM in the tanks with various radiuses leads in Fig. 2 by applying a proper pump and on the condition, that effective flow of Reference[5] is used for calculation. The curve (Fig. 2) indicates that necessary time for complete mixing has a reverse relation with the radius of the tank. It has obviously seen that RJM is more practical in larger radiuses and causes less mixing time. Furthermore, the effective flow depended on tank radius; in addition, a more powerful pump is needed in the large radius tanks, which include a RJM system having a nozzle with constant diameter (Fig. 3). The three points on the curve of Fig. 2 are the measured time in the three real constructed tanks placed at Kharg Island, which were obtained after mixing test.

STUDYING THE EFFECT OF NOZZLE DIAMETER ON MIXING TIME

According to Fig. 4a, by using relation 8 and if changes in mixing time obtained in terms of changes in nozzle diameter so that increase in diameter of output nozzle causes mixing time reduction. In this case, by increasing the diameter of output nozzle a higher flow and a more powerful pump are required to keep the effective flow (Fig. 3). There are two choices regarding the economical issues, firstly, using a weaker pump in a longer time (smaller diameter nozzle) and secondly applying a stronger pump in a shorter time (larger nozzle diameter). By taking into account the high cost of energy consumption, using a pump with a higher flow will be more economical because although the pump is more expensive it will have considerable cost saving during a long time by decreasing the operating time of machine in a month.

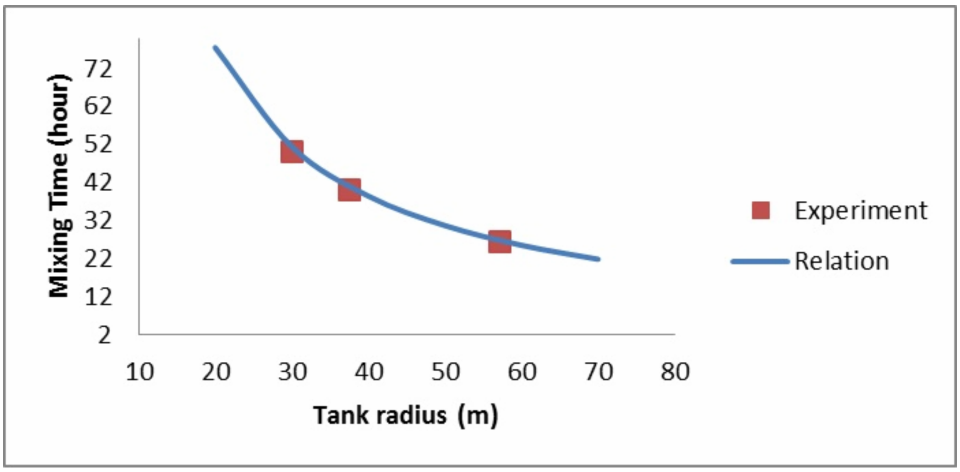


Fig. 2 – Measuring the mixing time of a RJM in the tanks with various radiuses (8 turns).

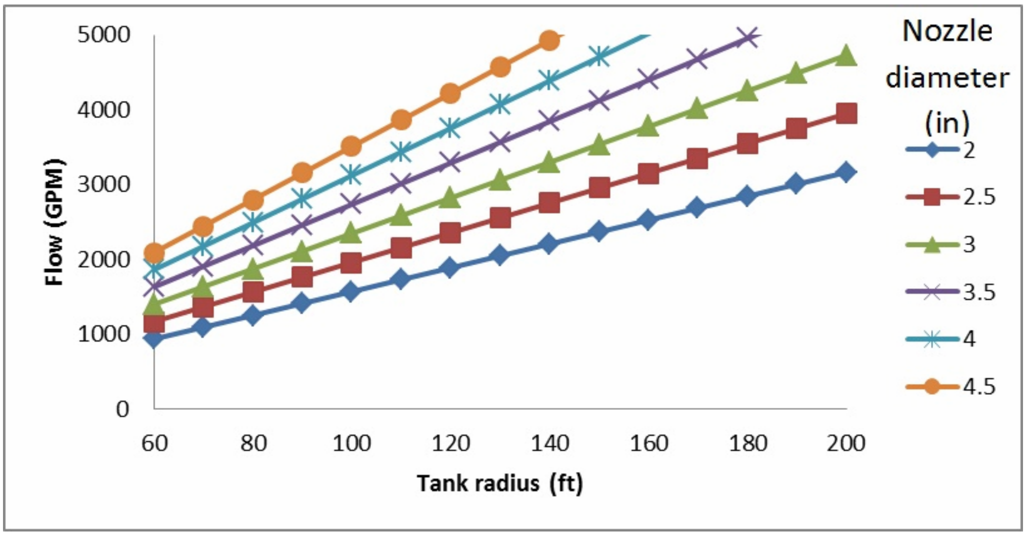


Fig. 3 – Effective flow increases with increasing the tank radius.

Table 3

Geometrical parameters of jet mixer

N.	Amount	Parameter
1	0.2	D
2	0.088	D_t
3	144184	I
4	0.1	d
5	20	θ
6	4	n
7	8	C

STUDYING THE EFFECT OF BLADES ANGLE OF TURBINE ON MIXING TIME

Increase in blades angle of turbine has two different effects on machine. First, increasing the angle results in faster rotation of blades and it causes faster total rotation of nozzle so that mixing time will be reduced.[9] This effect is obviously seen from the relation 7 and term "tag θ", by increasing θ, tag θ will increase and by increasing tag θ in this relation, t or mixing time will decrease. The second effect is that increasing the blades angle causes decreasing the slip coefficient of blades and by reduction in this amount blades rotation will be decreased. It is clearly recognized from the relations, by rising the θ in the relation 5, slip factor will decrease and by decreasing slip factor mixing time will increase it causes increase in mixing time. The effect of increasing the angle, which results in faster rotation of blades, is more significant than the effect of slip coefficient and finally increases in angle causes reduction in mixing time (Fig. 4b). In Table 4 rotary jet mixer velocity is compared between various references, nozzle rotary jet mixer in this paper is nearby references.[4,7,12] Companies can reach these velocities by varying the blade angle.

Table 4

Rotary jet mixer velocity comparison between references

N.	Nozzle rotation velocity (degree. min.)	Blade angle◦ (degree)	Reference
1	1.79 to 5.04	20 to 50	Mixing time (relation 8)
2	1.78 to 5.18	30 to 65	P43 company [8]
3	1.78 to 5.18	15 to 45	Win company [7]
4	1.5 to 3.5	-	Industrial mixing handbook [5]
5	2 to 3	-	TGK company [10]

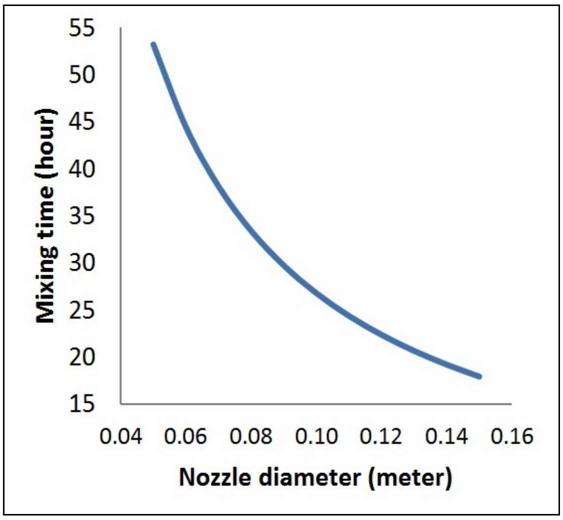


Fig. 4a – Changes in mixing time with nozzle diameter with blades angle.

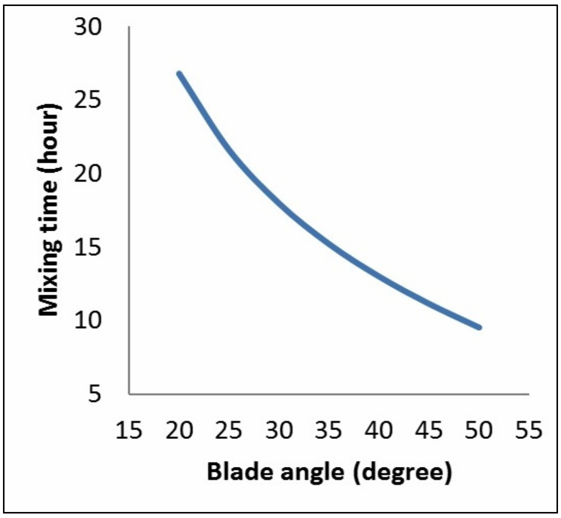


Fig. 4b – Changes in mixing time.

COMPUTATIONAL FLUID DYNAMICS (CFD) WITH FLUENT SOFTWARE

A tank with the diameter of 114 m, height of 17 m, and nozzle with a diameter of 100 m that contains crude oil with 0.858 viscosity was modeled by CFD method (Fig. 5). After modeling and gaining the results, effective length of jet was determined as a main parameter in mixing time. Researchers have their own ideas about the effective length; here it is measured 7 m. If the last relation of Table 1 is used and effective length is put in the previous relations the approximate mixing time will be calculated. This amount is 26 h that nearly equals the time obtained by relation 8 in the present study, which is 28 h (Table 5).

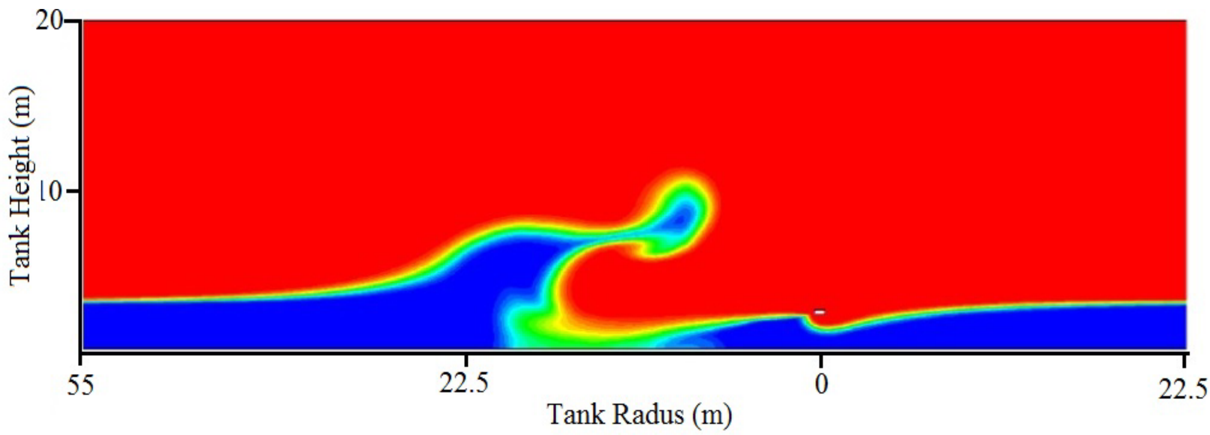


Fig. 5 – CFD analysis with FLUENT software on the crude oil tank.

Table 5

Comparing the mixing time[10]

Tank diameter (m)	Mixing time (relation 8) (hr.)	Mixing time (last relation-Table 1) (hr.)	Mixing time (Win Company) (hr.)	Mixing time (US Patent) (hr.)	Mixing time of the 130 mm nozzle (TGK) (hr.)	Mixing time of the 130 mm nozzle (relation 8) (hr.)
114	28	26	26	-	24	22
85	38	-	-	36	-	-
60	54	51	50	-	-	-

Table 6

Effective length of the jet in a tank with diameter 60m

Distance from nozzle (m)	P43		Win	
	Relative energy (%)	Velocity (m/s)	Relative energy (%)	Velocity (m/s)
5	1.087	2.474	2.920	1.514
2.5	4.347	4.948	5.146	4.703
1	27.170	12.369	14.640	38.062

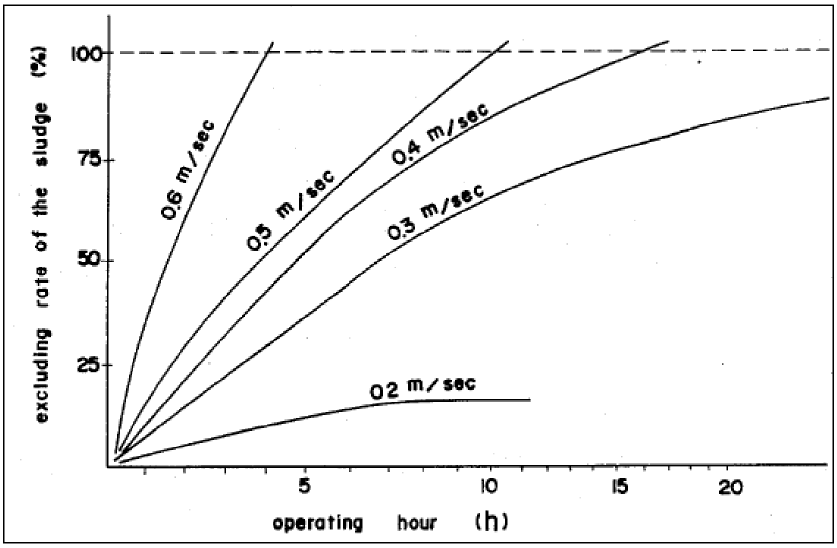


Fig. 6 – Mixing time of a tank with diameter 85 m.[11]

THE RESULTS OBTAINED BY THE MANUFACTURE COMPANIES OF SRJ MACHINE

The manufacturer company P43 has been given relation 9 to measure the velocity in each arbitrary distance from the jet of the tank:

$$U = 0.1776 \times \frac{Q}{KD} \quad (9)$$

In this relation, U is the linear velocity (ft/s) of jet at k (ft) distance from the nozzle with diameter D (in) and flow Q (Gal/min). If jetted fluid velocity inside the tank is measured at different distances from nozzle, then jet energy ($1/2\ U^2$) is calculated relative to primary output energy of jet at various distances from nozzle, it comes to the results of Table 6. The velocity was also measured at different distances in real working situation by Win Company and some of the relevant data are seen in this table. If the effective length is presumed as a length in which the jet energy approximately comes to 5% of the primary energy, this length will be 2.5 m in a tank with diameter of 60m (Table 5). If this length (2.5 m) is put in relation 8 of the Table 1, mixing time will be 51 h that is very close to 54h which obtained by the relation of this survey. According to Fig. 6, the curve has been drawn for a tank with a diameter of 85m and by considering the minimum velocity 0.3 m/s to break the sludge construction, the mixing time will be 36h approximately 100% mixing. If relation 8 is used, the mixing time will be 38 h so there is a little difference between these two amounts.

Therefore, this relation is well proved in another way. TGK Company has designed a RJM system with a nozzle diameter of 130mm for a tank with diameter 114 m and the required time for a complete turn has been estimated 180min. If eight complete turns were needed, mixing time would be 24 h. On the other hand, by using relation eight for a tank with diameter 114 m, which has a nozzle with 130 mm in diameter mixing time, will be 22 h. So there is no much difference between these two amounts and the relation is proved again.

CONCLUSIONS

By considering the necessity of a relation for mixing time of Rotary Jet Mixers (RJM), the present study responds to it in effective way and its accuracy has been proved with several methods (comparative Table 5). Then, by the use of this relation, the effect of three main variable design parameters, tank size (diameter), nozzle radius, and blade angle of turbine, on mixing time has been studied. Mixing time is one of the most important parameter to design RJM. Finally the following conclusions have been reached:

Using RJM in large-scale oil tanks is preferable for the tanks with small radius because besides reduction in mixing time, a pump with higher flow will be needed so it is more economical in comparison with a weaker pump that causes increase in mixing time. Moreover, by increasing the flow and input pressure, higher resistance and more qualified pieces should be taken into account.

Increase in diameter of output nozzle has similar results. Rising the diameter causes reduction in mixing time so it's necessary to use a pump with a higher flow and a more powerful machine.

Increasing the blade angle without any increase in flow causes faster rotation of blades and decreasing of mixing time. In this case, designing the turbine and turbine shaft is more complicated because of the considerable practical moment so that a stronger turbine is required.

List of notations in the main relations

N.	Parameter	Notations
1	Effective Flow	Q
2	Velocity of input Flow	V
3	Pitch speed of turbine	vt
4	Rotational velocity	N
5	Slip factor of blades	γ
6	Revolution of RJM	t_1
7	Mixing time	t
8	Diameter of RJM input	D
9	Diameter of RJM Turbine input	Dt
10	Total reduction ratio of Gearbox	I
11	The required turns for proper mixing	C
12	Constant number of unitary transformation	U
13	Output diameter of RJM nozzle	d
14	Tank radius	R
15	Tank Height	H
16	Deviation angle of RJM turbine blades	θ
17	Blade number of RJM turbine	Z

REFERENCES

1. M. G. Heath and A. R. Heath, *Acta Montanistica Slovaca Ročník*, **2004**, *9*, 184.
2. H. D. Zughbi and M. A. Rakib, *Chem. Engineering Scie.*, **2004**, *59*, 829.
3. Wolf S. Jayanti and G. F. Hewitt, *Chem. Engineering Scie.***,** **2001**, *56*, 3221.
4. K. L. Wasewar, *J. Chem. & Biochem. Engineering Quarterly*, **2006**, *20*, 31.
5. L. P. Edward A. A. Victor and M. K. Suzanne, "Handbook of industrial mixing science and practice", John Wiley & Sons, 2004.
6. J. Earl Logan and R. Ramendra, "Handbook of turbo machinery", 2003.
7. Corporation Win, Model: WJT2000B, Korea Patent: 0219240, "Rotary jet mixer technical information", 2011.
8. P43, "Submerged rotary jet mixer", Operator's Manual, VEOLIA Environmental services, 2011.
9. N. Okita and Y.Oyama, *Japan. J. Chem. Engineers*, **1963**, *31*, 92.
10. "CMJ Systems", Toko Giken Industries co LTD, **2013.**
11. M. Nobuyuki and G. Takahiro, US Patent 4642138, "Method of preventing Deposition of Sludge in Liquid Tank and of Removing Deposition Sludge", 1987.
12. W. Patwardhan, *Chem. Engineering Sci.*, **2002**, *57*, 1307.