A PROPOSAL FOR WASHING TOP LAYERS OF SAND FILTERS USING AQUA JET PUMP SCRUBBER

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ABSTRACT

Sand filters have been used for a long time for the final treatment of drinking water. There is also an increasing need for sand filters as a final treatment stage in waste water treatment plants due to more stringent requirements on the quality of the treated water.

Clogging of sand filters by impurities materials affects their performance, particularly for that used in the final treatment of drinking water applications. Vigorous aqua scrubbing of sand filters top layers can break such impurities up into suspended materials and discharges it outward sand filters.

A proposal for washing sand filters top layers using aqua jet pump scrubber was the target of this research. The aqua jet pump scrubber is designed potentially with significant technical and economical advantages compared to other conventional washing techniques. Aqua jet pump scrubber can enhances significantly the sand filter performance and improves the quality of drinking water by removing suspended impurities.

The aqua jet pump scrubber has proven to be very economical and efficient solution for the removal of impurities from contaminated-sand. It is simple in operation, and only minimal maintenance is required at planned shutdowns.

KEYWORDS:

Sand filter, Jet pump, Scrubber

INTRODUCTION

Filtration is a physical, chemical, and (in some instances) biological process for separating suspended impurities from water by passage through porous media. Two general types of filters are commonly used in water treatment; the slow sand filter and the rapid filter. A slow sand filter consists of a layer of ungraded, fine sand through which water is filtered at a low rate; the filter is cleaned by periodically scraping a thin layer of dirty sand from the surface at intervals of several weeks to months. The sand is washed and after several scrapings, returned to filter [1]. A rapid filter, on the other hand, consists of a layer of graded sand, or in some instances, a layer of coarse filter media (e.g., anthracite) placed on top of a layer of sand, through which water is filtered at much higher rates; the filter is cleaned by back washing with water.

One important phase of the operation of a sand filter concerns the regular washing of suspended matter retained in the sand. The extended use of sand filters will imply a significantly increased load of suspended particles on the filter. Lennart [2] explained a method for washing rapid sand filters using water jets. The method utilizes strong water jets penetrating the filter sand from above fluidizing part of the sand and thus washing it.

Hydro-cycloning by single or multiple systems, in which the heavier and mostly cleaner coarse sand particles are separated from the finer and more contaminated-sand particles, one of the most frequently applied techniques for cleaning. The costs of the above processes are highly dependent on the level of purification required, the methods chosen and the type of contamination. Often more than one system must be applied in sequence to obtain an acceptably clean sand. The costs of cleaning each cubic meter of sand vary between a minimum of five dollars per cubic meter for one stage hydro-cyclone separation and a simply contaminated-sand, to 100 dollars per cubic meter for highly complex contaminated-sand cleaned by multiple systems.

Application range of wet scrubbing technology is wide. Wakefield [3] explained that vigorous scrubbing can break such material down into colloidal clay. The wet scrubbers in operation have shown several advantages that can be achieved. Lammentausta et al [4] proved that wet scrubbers have proven to be very economical and efficient solutions for various gas handling purposes, especially in case of removal of impurities from gases and heat recovery.

The paper suggests the application of aqua jet pump scrubber to a problem traditionally solved by barrel washer, paddle scrubber or simple pump and cyclone for cleaning sand filters top layers from the contaminated-materials and impurities.

THEORETICAL ANALYSIS

A jet pump works by transferring energy and momentum from a fast stream of fluid emitted from a nozzle to fluid surrounding the jet. This entrainment is by shear process depending on viscosity. The combined flow is collected by a mixing chamber in which energy is shared completely between the two streams.

It can easily be shown, e.g. Stepanoff [5], that maximum jet pump efficiency occurs when momentum is conserved. If we accept this, then consider two streams impact without rebound, momentum is conserved as follows:

$$m_1v_1 + m_2v_2 = m_3v_3 \tag{1}$$

If the second stream is stationary, i.e. $v_2 = 0$, and taking $M = m_2/m_1$ then

$m_3 = (1+M)m_1$ and equation (1) reduces to:

$$v_1 = (1+M)v_3 \tag{2}$$

and as the kinetic energy is $E = ½\, mv^2$, therefore:

$$E_1 = ½\, m_1v_1^2 \tag{3}$$

and $$E_3 = ½\, m_3v_3^2 = ½\, m_1v_1^2\,(1+M)/(1+M)^2 \tag{4}$$

The ratio between both kinetic energies is as follows:

$$E_3/E_1 = (1+M)/(1+2M+M^2) \tag{5}$$

Equation (5) can be represented on a diagram like that shown in Figure (1) to explain the variation of the ratio between both kinetic energies versus different flow ratios. It is clear from the figure that half the kinetic energy has been lost in the impact at M=1. This half is consumed totally in turbulence within the entrainment zone and mixing chamber. The same apply for the ratios of M=0.5, 1.5 & 2 where the loss in these cases are 33%, 60% & 67% respectively.
Basis theory, e.g. Stepanoff [5], drives:

$$1+M = \sqrt{R} \tag{6}$$

at maximum efficiency, if we neglect internal losses to friction etc. Thus we can add the curve which represents R versus M on the same diagram of Figure (1).

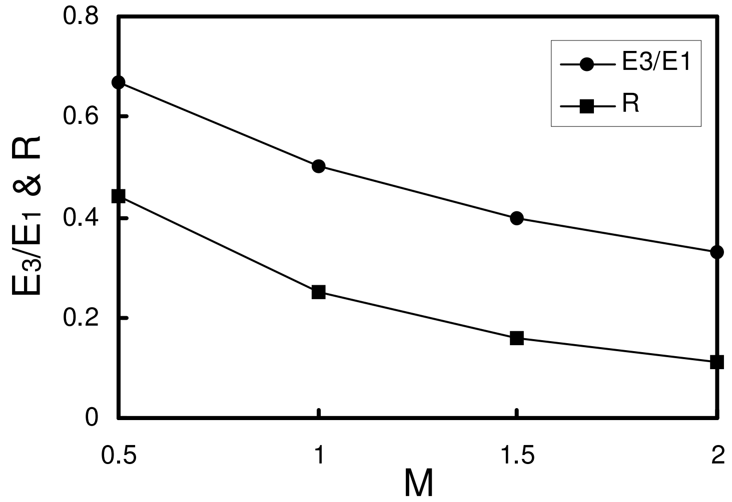
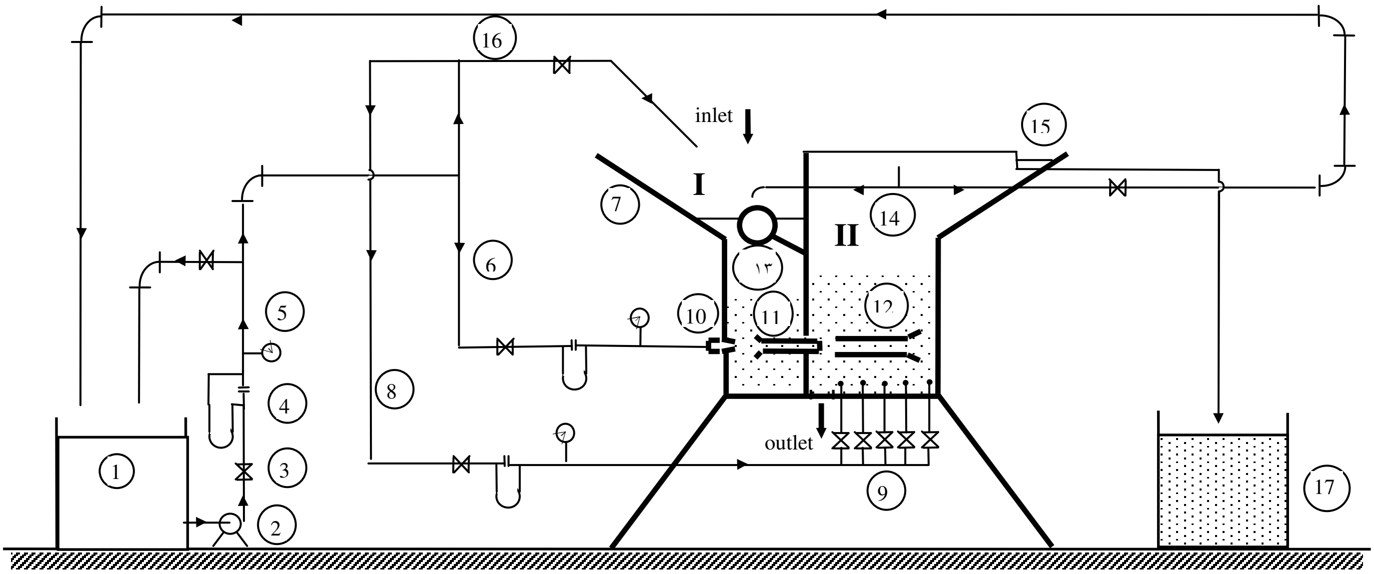


Fig. (1): Ratio between both kinetic energies, area ratio versus flow ratio

EXPERIMENTAL APPARATUS AND TESTING PROCEDURE

The experimental apparatus shown in Figure (2) is specially designed and constructed to evaluate the performance of the aqua jet pump scrubber. It consists of the main tank (1), which supplies water via a one inch pipeline for two centrifugal pumps (2) connected in series. Each pump is driven by an electric motor, delivering 9.6 m^3/h of water against a maximum head of 30 m H_2O. Pumped water flows to a gate valve (3) and then to a calibrated orifice flow meter (4) connected to a U-tube mercury manometer followed by a pressure gage (5) and then it flows to a one inch tee-connection. The tee-connection divides the flow into two branches; a bypass secondary branch to the main tank and another main branch for the driving, elutration and spray bars flows. The last main branch is connected to another one inch tee-connection which divides the water flow into two sub-branches; one sub-branch for the driving motive flow (6) of the aqua jet pump scrubber (7) and another sub-branch (8) for the spray bars (9).

The aqua jet pump scrubber consists of two chambers connected to each other and separated by a partition from the inside part. The left chamber [I] equipped by the first controllable nozzle (10) of 10 mm inner diameter, which consists with the first fixed diffuser (11) of 20 mm inner diameter; the first jet pump. This jet pump entrains the contaminated-sand which introduced from the top of chamber [I] and delivers it to the right chamber [II]. Two different diffusers are tested; one of them {A} with constant cross sectional area along the stream line of 20 mm exit inner diameter and the other {B} with enlarged cross sectional area of 23 mm exit inner diameter.



1 Main tank
2 Centrifugal pump
3 Gate valve
4 Orifice meter
5 Pressure gauge
6 Motive flow line
7 Scrubber
8 Spray bars line
9 Spray bars
10 First nozzle
11 First diffuser (second nozzle)
12 Second diffuser
13 Float
14 Bypass line
15 Weir
16 Elutration line
17 Collect tank

Fig. (2): Schematic of the experimental apparatus including aqua jet pump scrubber

The first diffuser is considered as a second nozzle and it consists with the second movable diffuser (12) of 46 mm inlet inner diameter and 73 mm exit inner diameter; the second jet pump. A float (13) is used to control flow from the bypass line (14) towards the left chamber. A weir (15) at the top of the right chamber is used for separating contaminant material floated on the surface of water. The elutration branch (16) is used to mix contaminated-sand with water. The contaminant material is collected in a separate tank (17). There is no extraction facility from the scrubber. The clean sand simply discharges under gravity from the exit hole.

THE CONTAMINATED-SAND SAMPLES PREPARATION

Preparation of the tested samples which simulates the contaminated-sand was done using quartz sand type namely between less than 4.8 mm to 0.03 mm particle diameter with d_{50} of 0.52 mm as a primary clean medium and lime, iron oxide and residue oil as a secondary contaminants medium. Both mediums are mixed together to form the tested samples as follows:

Percentage of contaminants per one kilogram of quartz sand before test for all secondary mediums equals 6 %.

RESULTS AND DISCUSSION

Normally all the contaminated-sand is arranged to pass once through the first jet pump and several times through the second jet pump. The particles are subjected to vigorous rubbing and inter-particles impact of the first, high speed jet. The aqua jet pump scrubbing mechanism is to introduce cavitation in the jet of the first jet pump as it expands from nozzle to mixing chamber, and also during momentum sharing [6]. At water supply pressures, the extreme vorticity involved in the momentum transfer causes vigorous cavitation and abrasion. A proportion of cavitation bubbles collapse on the contaminated-sand particles, augmenting the scrubbing action.

Figure (3) shows a photograph of top view of the aqua jet pump scrubber where the partition which separates between the two chambers [I] & [II]. The photograph shows also the vigorous mixing and entrainment which occurs at the outlet from the first jet pump.

Fig. (3): Photograph of top view of the aqua jet pump scrubber where partition which separates between the two chambers [I] & [II]

The relation between the entrained contaminated-sand versus motive pressure of the first jet pump using two different diffusers {A} & {B} is shown in Figure (4). Its clear from the figure that diffuser {B} behaves efficiently compared to diffuser {A}, this may be attributed to the constant cross sectional area along the stream line for diffuser {A} which limits the flow specially for the range of low driving pressure. Both diffusers entrain the same value approximately of contaminated-sand at higher driving pressures.

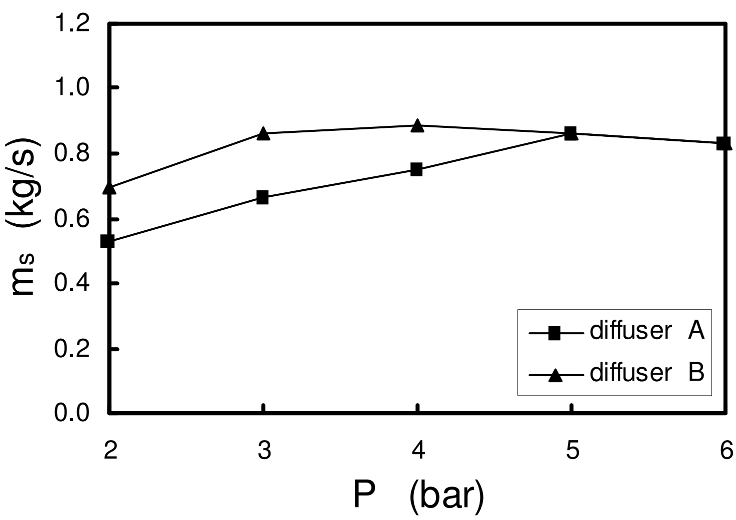


Fig. (4): Entrained contaminated-sand versus motive pressure using two different diffusers

Figure (5) shows the variation of first jet pump efficiency versus flow ratio using the two different diffusers {A} & {B}. The efficiency using diffuser {A} is better compared to the efficiency using diffuser {B} and this may be attributed to kinetic energy lost in impact within entrainment zone and mixing chamber is higher in diffuser {B} compared to that in diffuser {A}. This kinetic energy is consumed totally in turbulence.

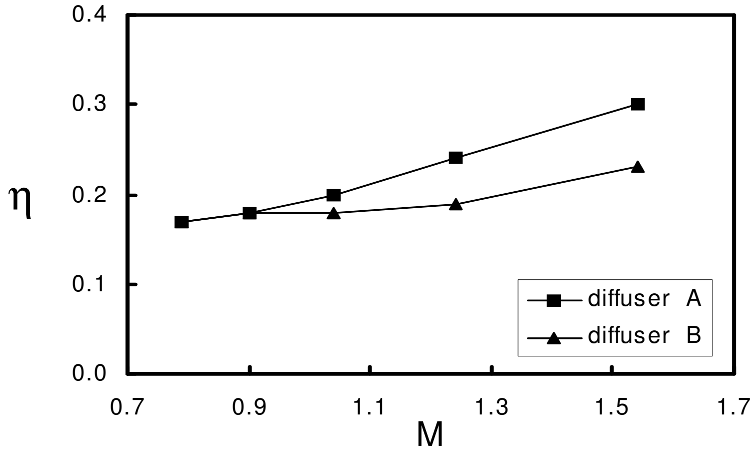


Fig. (5): The first jet pump efficiency versus flow ratio using two different diffusers

Power input into the pumps which drives the aqua jet pump scrubber is 2.24 kW giving 60 m H_2O total head, including a little for the elutriator or upward current spray bars. Comparing the costs of power for aqua jet pump scrubber to the costs of replacing sand completely or the costs of other conventional washing techniques; proves the economical advantages of that proposal.

Measurement of the specific energy (energy consumed per unit mass of product) required to achieve the desired cleanliness is important. The specific energy consumed during aqua jet pump scrubbing process per entrained contaminated-sand for different motive pressures are shown in Fig. (6) for both diffusers. The specific energy consumed using diffuser {B} is less than that of {A} for the driving pressure range from 1 to 5 bar. Both diffusers have the same value approximately after the driving pressure of 5 bar. This may be attributed to the increase of power required using diffuser {A} to overcome increase of vigorous motion during entrainment of excess amounts.

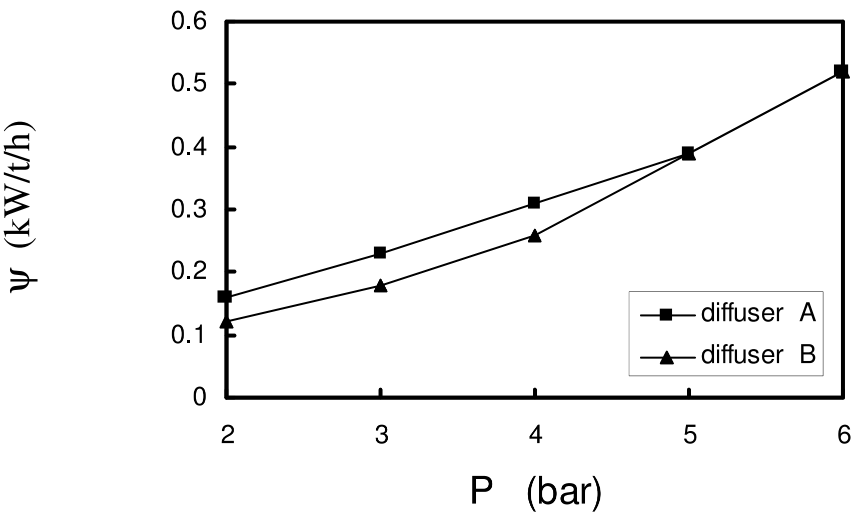


Fig. (6): The specific energy consumed during scrubbing process per entrained contaminated-sand for both diffusers

Figure (7) represents the percentage lime content versus driving pressure of the aqua jet pump scrubber using both diffusers {A} & {B}. It is clear from the curve the decrease of lime as pressure increases gradually. Both diffusers gives the same cleaning action approximately without noticeable difference between them. This may be attributed due to fine grains of lime which creates difficulty to separate it from sand besides dissolved lime grains in water.

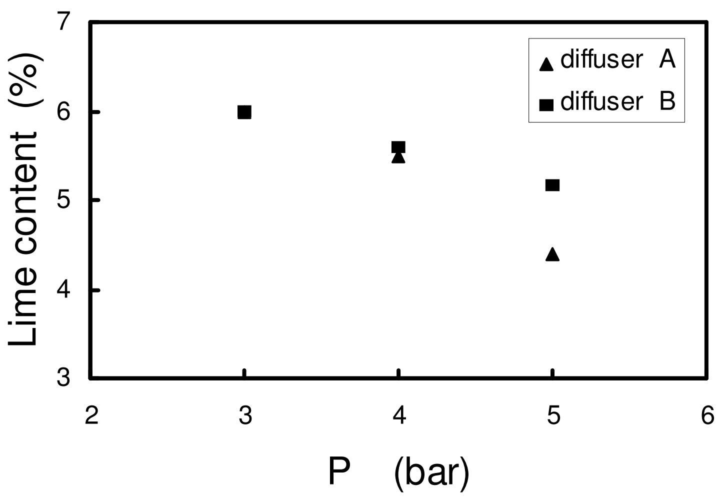


Fig. (7) Percentage of lime content versus driving pressure

Figure (8) shows the percentage of iron oxide content versus driving pressure of the aqua jet pump scrubber using both diffusers. The decrease of iron oxide as pressure increases is noticeable here for both diffusers. Diffuser {B} behaves efficiently compared to diffuser {A} under the same working conditions.

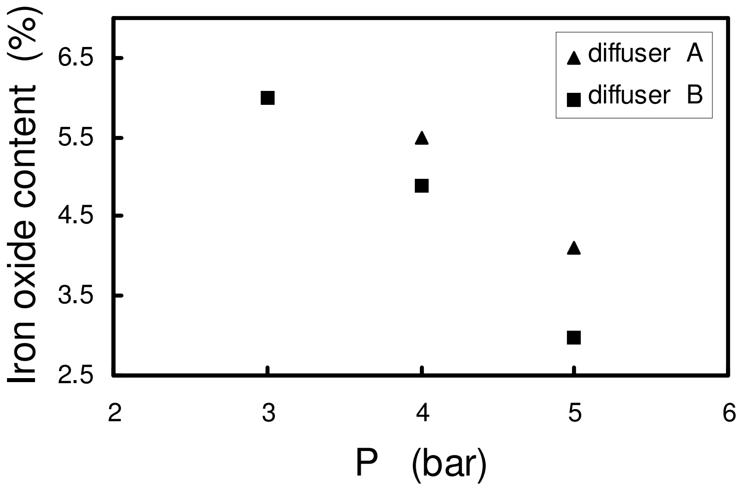


Fig. (8) Percentage of iron oxide content versus driving pressure

The same behavior is noticeable in case of sand which is mixed with residue oil content. This may be due to the constant cross sectional area along the stream line of diffuser {A} which limits the induced flow compared to the enlarged cross sectional area of diffuser {B} as shown in Figure (9).

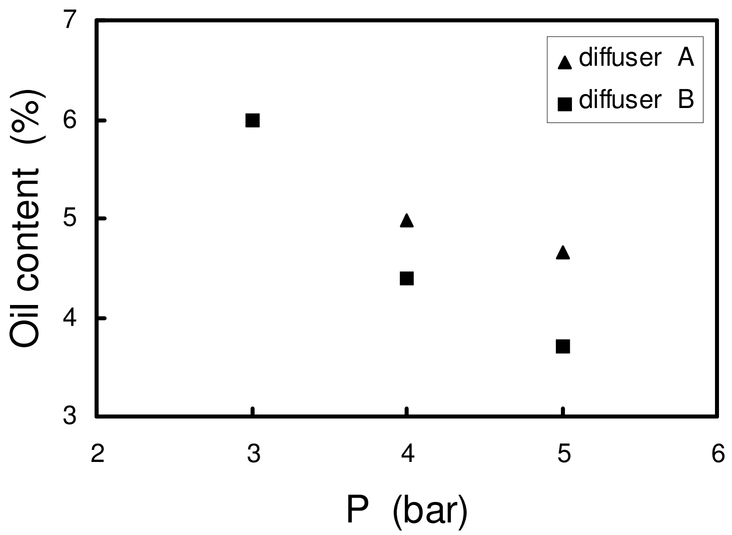


Fig. (9) Percentage of residue oil content versus driving pressure

The reduction in lime, iron oxide and residue oil are encouraging, being far better than anything achieved by mechanical scrubbing.

CONCLUSIONS

1- The aqua jet pump scrubber proved the ability to remove lime, iron oxide and residue oil from the tested samples which simulates the contaminated-sand successfully.
2- Increasing the driving pressure of the aqua jet pump scrubber decreases the percentage contents of the contaminants.
3- Power input into the pumps which drives the aqua jet pump scrubber is 2.24 kW giving 60 m H_2O total head, including a little for the elutriator or upward current spray bars.
4- The aqua jet pump scrubber is simple in operation, and only minimal maintenance is required at planned shutdowns.
5- If the sand requires a second scrub it must be recovered from the outlet hole and fed in again at inlet chamber.
6- Aqua jet pump scrubber can enhances significantly the sand filter performance and improves the quality of drinking water by removing suspended impurities.

ACKNOWLEDGEMENT

The technical support of the Canal Naval Construction Co. affiliated to Suez Canal Authority is greatly acknowledged. The author is grateful to Mr. Tony Wakefield for encouraging the experiments in this field and for his continuous active cooperation.

NOMENCLATURE

A_1	motive flow nozzle area	(m^2)
A_2	mixing chamber area	(m^2)
d_n	diameter of nozzle	(m)
d_m	diameter of mixing tube	(m)
E	kinetic energy = $\frac{1}{2} mv^2$	(J)
M	flow ratio = Q_2/Q_1	(-)
m	mass flow rate	(kg/s)
m_s	entrained solid material flow rate	(kg/s)
p	motive pressure	(bar)
R	area ratio = d_n^2/d_m^2	(-)
Q_2	induced flow rate	(m^3/s)
Q_1	motive flow rate	(m^3/s)
v	velocity	(m/s)
ψ	specific energy consumed	(kW/t/h)
η	first jet pump efficiency	(-)

Subscript: $_{1,2,3}$ for motive, induced & delivery streams

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